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THESIS

THE DEVELOPMENT OF SCHEDULED
MAINTENANCE PROGRAMS
FOR NAVAL AIRCRAFT

by

Charles Vincent Rose

June 1984

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Current processes for determining maintenance requirements are reviewed in some detail to promote understanding of how the logic system works, and how it interacts with the design process.

Major system acquisition and logistic support analysis processes are briefly summarized to highlight the location of the maintenance requirements determination procedures within the total system.

Comparisons are made and differences are noted between the U.S. Air Force procedures for maintenance program development and those of the Navy.

Potential problems with the new system of statistical sampling based depot maintenance are noted, and possible future developments in the field are discussed.

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The Development of Scheduled Maintenance Programs for Naval Aircraft

by

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B.S. San Diego State College, 1965
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LIST OF ACRONYMS

ACI	Analytical Condition Inspection
ACMR	Air Combat Maneuvering Range
AFB	Airframe Bulletin
AMP	Analytical Maintenance Program
AFLC	Air Force Logistic Center
AEP	Age Exploration Program
BIT	Built in Test
CAD	Computer Aided Design
DAE	Defense Acquisition Executive
DEM/VAL	Demonstration and Validation
DOD	Department of Defense
DSARC	Defense Systems Acquisition Review Council
FAA	Federal Aviation Agency
FME&CA	Failure Modes, Effects and Criticality Analysis
FSD	Full Scale Development
I Level	Intermediate Level Maintenance
ILS	Integrated Logistic Support
IOC	Initial Operating Capability
JMSNS	Justification for Major System New Start
LCC	Life Cycle Cost
LOR	Level of Repair
LRU	Line Replaceable Unit
LSA	Logistic Support Analysis

LSAR	Logistic Support Analysis Record
MIL-HDBK	Military Handbook
MIL-STD	Military Standard
MMH	Maintenance Man-Hour
MMH/FH	Maintenance Man-Hours Per Flight-Hour
MRA&L	Manpower, Reserve Affairs & Logistics
MRC	Maintenance Requirement Card
MRRB	Maintenance Requirements Review Board
MSG	Maintenance Steering Group
NDI	Non-Destructive Inspection
NESO	NAVAIR Engineering Support Office
O Level	Organizational Level Maintenance
OMB	Office of Management and Budget
OSD	Office of the Secretary of Defense
PDM	Program Decision Memorandum
POM	Program Objectives Memorandum
PPBS	Planning, Programming and Budgeting System
RCM	Reliability-Centered Maintenance
ROR	Repair of Repairables
SDLM	Standard Depot Level Maintenance
SEC NAV	Secretary of the Navy
SM	System Manager
SM&R	Source, Maintainability, and Recovery Code
SoD	Secretary of Defense
UAL	United Airlines
USAF	United States Air Force

I. INTRODUCTION

A. THE EVOLUTION OF AIRCRAFT DESIGN AND MAINTENANCE

The evolution of aircraft design has been rapid since its origin in 1903, and this is especially true for the period subsequent to World War II up to 1984. Aircraft have increased in complexity, sophistication, and redundancy, with each generation.

Maintenance requirements and procedures have also grown in sophistication and complexity with time in order to keep aircraft operating safely and efficiently.

The evolution of aircraft design has been along several lines, including commercial, military, and private aviation. Maintenance procedures, programs, and philosophies have also varied as the field of aviation has grown. The result of this continued growth is the ever broadening and ever more complex field of aircraft maintenance existing in 1984. This field now requires knowledge and skills comparable to those required to design an aircraft.

B. INTENT OF THE THESIS

The current knowledge base for effective aircraft maintenance results from background and knowledge of successes and failures of the past, emerging technologies and

maintenance practices of the present, and potential maintenance needs and performance requirements of the future.

This report summarizes parts of the current knowledge base pertinent to military aircraft maintenance programs. Many people in the field of aviation are not aware of the depth and breadth of the analytical effort that goes into arriving at a scheduled maintenance program. Many are also not aware of the reasons behind the changes leading to the current practices for determining scheduled maintaining requirements. To improve the level of understanding of people inside and outside the field of aviation, previous practices and the history of the development of the current process are reviewed to show why and how changes occurred.

It is hoped that this report will serve as an introduction for people interested in but not familiar with the subject area, allowing them to understand terminology and the basis of the logical process behind scheduled maintenance programs. It is also intended that the report will provide the person with experience in any of the disciplines involved with maintenance programs (engineering design, logistics, program cost analysis, etc.) a better understanding of the overall process, and how and why the various pieces fit together.

C. THE INFLUENCE OF ECONOMIC FACTORS ON MAINTENANCE PROGRAMS

A major factor driving the development of the current procedures for determining scheduled maintenance requirements has been economic pressure. As equipment becomes more complex, it can also become more expensive to maintain unless specific steps are taken during the design process to provide reliability and maintainability. Funding for performing maintenance has become more scarce over the years as the cost of procuring new equipment has grown, and available funding has migrated towards acquisition. The reduction of available funding has caused all maintenance requirements to be looked at carefully, and has forced the development of a rigorous system for justifying these requirements. It has been said with some validity that the wide bodied commercial jets would not have been economically feasible to operate under the maintenance programs in use prior to the development of a logic system for determining scheduled maintenance requirements. This statement is at least partially applicable to military aircraft and the need to reduce maintenance expenditures for them.

In a statically based sampling inspection program only a statistically significant percentage of an aircraft fleet is inspected at the depot to monitor fleet material condition. The savings resulting from changing to a sampling inspection program of scheduled depot maintenance are enormous, but whether or not this change can be made depends upon the

original design. Sampling based inspection programs are becoming an economic necessity if funding is to be available for acquiring new weapon systems as well as maintaining the old ones, and this in turn requires interaction between the designer and the maintenance analyst during the design process. At the same time, readiness and safety must be maintained at acceptable levels. The current system and procedures for determining scheduled maintenance requirements should accomplish these goals.

D. MAJOR TOPICS ADDRESSED

This report provides the reader a synopsis of the history of aircraft scheduled maintenance practices in general, and U.S. Navy aircraft scheduled maintenance practices in particular. The principal events leading up to the current system of developing a scheduled maintenance program are noted, and current practices are examined. Major topics addressed are:

1. History and Background

The major events in the growth of the field of scheduled maintenance requirements determination are noted for the period subsequent to World War II up to 1984. This information provides the reader with the why and how of the development of the current system of scheduled maintenance program requirements determination. By examining the roots

of aviation scheduled maintenance programs a clearer understanding of the current system may be attained.

2. The Acquisition Process

The relationship between the acquisition of a major aircraft weapon system and the development of its scheduled maintenance program is examined. The impact of maintainability, reliability, life cycle costs, and logistics support analysis requirements on the process are reviewed. The nature of this relationship is unclear to many people in the aviation field; however, this area will have significant impact on the design of all future weapon systems.

3. Reliability-Centered Maintenance

The use of Reliability-Centered Maintenance (RCM) analysis logic techniques in the determination of scheduled maintenance requirements is examined. The details of the logic are presented for information, and the principles behind the logic are reviewed. A better understanding of the methodology used to determine scheduled maintenance requirements should be useful to everyone in the aviation field. Many aircraft designers in particular can gain by better understanding the logic and its potential impact on a design since it appears likely that RCM will interact with and impact all future designs.

4. The F/A-18 Scheduled Maintenance Program

Current practices in developing an aircraft maintenance program are examined as they relate to the F/A-18

aircraft now entering full-scale production and fleet deployment. Operating data for the Navy's newest fighter aircraft are compared to the data for the F-4 and F-14 to illustrate the impact of considering maintenance and logistics requirements early in the design process. The tremendous expense of a program that requires all aircraft to pass through a depot facility every few years for disassembly and inspection is compared to a less expensive statistical sampling inspection program wherein only a representative sample is examined each year.

5. Air Force Maintenance Programs

Current United States Air Force practices in aircraft scheduled maintenance programs are examined to note differences and similarities relative to Navy practices, and to speculate on the reasons for the differences.

6. Potential Problems

Major differences between the current system of scheduled maintenance requirements and previous practices are reviewed, and advantages and potential problems compared. The advantages appear to greatly exceed the disadvantages if reasoned efforts are made to control potential problems.

7. Future Directions for Scheduled Maintenance Programs

A look at probable future developments is included to identify work still needing to be done in the field and changes that are likely to occur.

II. BACKGROUND

A. THE EARLY YEARS OF AVIATION MAINTENANCE

In the beginnings of aviation, aircraft were relatively simple machines with very low reliability. Scheduled maintenance often consisted of essentially rebuilding the vehicle for each flight. As the sophistication and complexity of the machines increased, the intervals for rebuilding the components increased, but the basic maintenance philosophy remained one of making the equipment like new to insure adequate reliability and safety in operation. This philosophy was in effect in one form or another through World War II.

B. AFTER WORLD WAR II

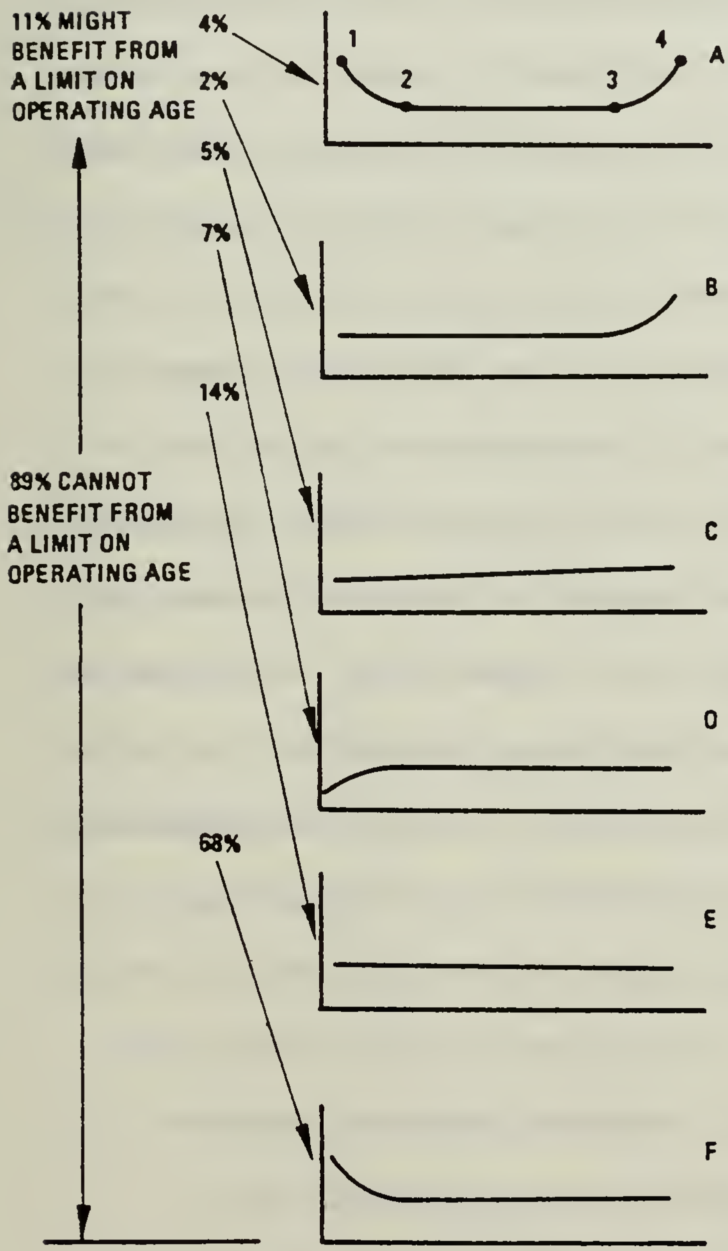
When commercial aviation started to grow rapidly and expand the data base available to people responsible for maintaining the equipment, some individuals began to question the philosophy of rebuilding or overhauling complicated equipment as a means of insuring reliability and safety. With the advent of turbojet aircraft of increased complexity and redundancy in the 1950s, it became more and more obvious to some that the concept of overhauling complicated equipments was of questionable benefit, both economically and from a safety and reliability standpoint.

C. THE FIRST JET TRANSPORTS

Soon after the introduction of the early jet transports (e.g., DC-8), studies of failure data on turbojet engines led to a decision to not overhaul engines on a scheduled basis in all cases. Failed engines were examined on an individual basis to see if overhaul was in fact necessary, and in the majority of cases any indicated repair was accomplished and the unit returned to service for the remainder of its operating life [Ref. 1; pp. 39].

As operating and failure data on the early jet transports became available, they provided a basis for deciding that mandatory overhaul at a set time was in fact not always desirable for complex equipments, from either an economic or safety and reliability standpoint. Examination of the family of curves shown in Figure 1 illustrates this point. Examination of failure data from all types of aviation equipments led to the curves shown. For specific equipment types in each curve, conditional probability of failure is plotted on the vertical axis against hours of operation since new or overhauled on the horizontal axis. Figure 1 is adapted from the landmark report on Reliability-Centered Maintenance (RCM) prepared for DOD by Nowlan and Heap [Ref. 1; pp. 46, Exhibit 2-13].

Age reliability patterns. In each case the vertical axis represents the conditional probability of failure and the horizontal axis represents operating age since manufacture, overhaul, or repair. These six curves are derived from reliability analyses conducted over a number of years, during which all items analyzed were found to be characterized by one or another of the age-reliability relationships shown. The percentages indicate the percentage of items studied that establish each of the basic patterns (United Airlines).



The bathtub curve; infant mortality, followed first by a constant or gradually increasing failure probability and then by a pronounced "wearout" region. An age limit may be desirable, provided a large number of units survive to the age at which wearout begins.

Constant or gradually increasing failure probability, followed by a pronounced wearout region. Once again, an age limit may be desirable (this curve is characteristic of aircraft reciprocating engines).

Gradually increasing failure probability, but with no identifiable wearout age. It is usually not desirable to impose an age limit in such cases (this curve is characterisitic of aircraft turbine engines).

Low failure probability when the item is new or just out of the shop, followed by a quick increase to a constant level.

Constant probability of failure at all ages (exponential survival distribution).

Infant mortality, followed by a constant or very slowly increasing failure probability (particularly applicable to electronic equipment).

FIGURE 1. AGE RELIABILITY PATTERNS

D. FAILURE DATA

Curve A in Figure 1 is the well-known "bathtub" curve often mentioned by failure analysts as a theoretical "ideal." This curve is somewhat similar to the kind of plots one gets from human actuarial data. Breaking the bathtub curve into significant segments leads to the "infant mortality curve" demonstrated by the segment from 1 to 2 on Curve A of Figure 1. The infant mortality curve illustrates the phenomenon of a high initial failure rate (the average number of failures per hour, or in some cases 1,000 hours) of complex equipment or human infants. After this initial period during which the "weaker" units die off at a relatively high rate, the curve stabilizes to a constant failure rate as shown on Curve A, segment 2 to 3. This idealized theoretical condition indicates that in this region of its lifetime the equipment fails randomly (as a random variable) with no evidence of deterioration relative to age (time in service). At the end of this "constant failure rate" segment, in segment 3 to 4, the idealized equipment starts to fail at an ever-increasing rate indicating some form of "wear out." Although the bathtub curve was originally thought to be indicative of the performance of all equipment, this didn't turn out be the case. In their landmark report Nowlan and Heap [Ref. 1] indicate that only four percent of a large group of equipments studied actually exhibited failure rate performance close to the idealized bathtub curve.

Curves B, C, D, E, and F of Figure 1 illustrate the other types of failure rate performance observed. Of primary significance when observing these curves is the preponderance of data showing no definite wear out point. Only six percent of the data (Curves A and B) indicate the possibility of a definite wear out point, an additional five percent show an increasing failure rate (Curve C), and 89 percent of the data show no definite wear out point. This is significant because it provides a basis for the decision not to overhaul equipments on a fixed time basis unless the failure data available strongly support the requirement by indicating a sharp increase in the failure rate at some specific age. As an example one can see by examining curve F of Figure 1 that removal of a component of this type from service for overhaul will only move the component back to the infant mortality portion of the curve where it has a higher failure rate. In this case a requirement to overhaul the component would actually increase the average failure rate as well as maintenance costs. Studies of the kind represented by the data in Figure 1 provided the basis for new thinking in the development of aviation maintenance programs.

E. THE DEVELOPMENT OF MSG-1

As reliability specialists became more knowledgeable about the failure tendencies and characteristics of the jet transports in service, time limits between overhauls were

extended and eventually deleted in the majority of cases for mechanical and electrical/electronic systems and equipments. Under the force of economic pressures to reduce maintenance costs as much as possible while maintaining safety and readiness at satisfactory levels, reliability specialists in commercial aviation started looking for ways to formalize the process of developing aircraft maintenance programs. This joint effort between the airlines, manufacturers, and the Federal Aviation Authority (FAA) lead to the formation of the Maintenance Steering Group (MSG) established in 1967 to develop a system for determining the maintenance requirements for the new "jumbo jet", the Boeing 747. The result of this effort was a systematic methodology for analyzing complex equipments and determining what scheduled maintenance was needed, if any, to allow the equipment to achieve its design level of reliability (reliability is defined as the probability that a device will perform in a satisfactory manner for a given period of time when operated under specified conditions [Ref. 2; pp. 14]). The methodology was based on the philosophy that maintenance in and of itself could not improve the level of reliability of complex equipment beyond its inherent design level. This procedure was tailored specifically for the 747 and was called MSG-1 [Ref. 3].

MSG-1 was successful in allowing the development of a scheduled maintenance program that started the 747 in service

with eight scheduled removal tasks as compared to the start of the DC-8 years earlier with 339 scheduled removal tasks [Ref. 1; pp. 386]. The tremendous conservatism in the initial requirements for the DC-8 was gradually overcome by extending the intervals on most of the components and systems as experience was gained, but this process was quite expensive as compared to starting with more realistic intervals, or no removal requirements at all.

F. THE POWER OF MSG-1

The power of the MSG-1 analysis process when used on a new design was the rapid feedback from the maintenance analyst to the designer. For the first time the designer could be aware of the downstream cost implications (maintenance and failure implications) of his design decisions early in the design process when changes are easiest and least expensive. Working as a design team, the design engineer and the maintenance analyst could produce an aircraft that would have not only the desired performance in terms of speed and range, etc., but one which would also be as easy to maintain as possible within technology and cost constraints. For the first time realistic tradeoff studies could be conducted to study the economic and safety impact of design alternatives.

G. THE DEVELOPMENT OF MSG-2

After the success of MSG-1, the joint group continued to work toward improving the procedures developed, making them more general and applicable to any aircraft. This effort lead to the creation of MSG-2 [Ref. 4] for application to the new wide-body jets, the Lockheed L1011 and Douglas DC-10, in 1970. Application of MSG-2 to the DC-10 resulted in seven scheduled removal tasks for the initial maintenance program [Ref. 1; pp. 386]. The procedures of MSG-2 were readily adaptable to the analysis of most aircraft, and were subsequently used to revise the scheduled maintenance programs for other commercial turbojet aircraft. Economic savings, increased availability, and no reduction in safety resulted. MSG-2 provided a logical process for analyzing a piece of equipment in terms of its significance to the functioning of a system; e.g., a hydraulic pump relative to the complete hydraulic system, and then to dependent aircraft functions (flight control system, flaps, landing gear actuation, braking, steering, etc.).

Significance of the component or system was judged on the potential impact of its failure. If the failure of the item had safety implications, a scheduled task was required unless the equipment would not benefit from the scheduled maintenance in terms of reduced likelihood of failure. If scheduled maintenance would not help reduce the consequences of failure to an acceptable level, redesign was required.

Figure 2 [Ref. 1; pp. 30, Exhibit 2.2] shows the relative importance of a failure is tied to the function of the item in the design.

For the first time maintenance requirements were having a direct input to the design of the equipment. This development was in part a recognition of the fact that well over half of the lifetime cost of owning and operating an aircraft is tied up in maintenance and operating expenses (some estimate more than 60 percent of total costs [Ref. 5; pp. 1-8]). Reducing maintenance costs could significantly lower the cost of owning and operating a fleet of aircraft. From this standpoint it can be seen that the potential gain from application of the procedures is much greater with a new design where iterations of redesign are more easily accomplished [Ref. 5; pp. 1-7]. For an existing design it is possible that the cost of applying the procedures would not be recovered in the remaining life of the aircraft program, and for this reason the procedures were not applied to some older aircraft programs.

H. NAVAL AIRCRAFT SCHEDULED MAINTENANCE PROGRAM DEVELOPMENTS

While commercial aviation was making great strides in reducing maintenance costs in the late 1960s and early 1970s, military aviation authorities were watching with interest and attempting to incorporate relevant ideas into their aviation maintenance system hoping to reduce costs. The Navy lead the

Nature of failure consequences

First Failure	Second Failure	Third Failure	Fourth Failure	Effect on Previous Failures in Sequence
Critical				The critical nature of the first failure supersedes the consequences of a possible second failure.
Operational	Critical			A second failure would be critical; the first failure must be corrected before further dispatch and therefore has operational consequences.
Nonoperational	Operational	Critical		A third failure would be critical; the second failure must be corrected before further dispatch, but correction of the first failure can be deferred to a convenient time and location.
Nonoperational	Nonoperational	Operational	Critical	A fourth failure would be critical; the third failure must be corrected before further dispatch, but correction of both the first and second failures can be deferred.

The consequences of a single failure as determined by the consequences of a possible multiple failure. A failure that does not in itself affect operating capability acquires operational consequences if a subsequent multiple failure would be critical.

FIGURE 2. FAILURE CONSEQUENCES

military application of MSG-2, first with the P-3 and S-3 patrol aircraft, and then with the F-4 fighter and the development of the Analytical Maintenance Program.

1. United Airlines and the P-3 and S-3

In 1972 and 1973 the Department of Defense (DOD) contracted with United Airlines (UAL) to apply the MSG-2 logic to the maintenance requirements for the P-3 and S-3 aircraft at the Naval Air Rework Facility, Alameda. This effort resulted in major changes to the maintenance programs for the P-3 and S-3.

2. United Airlines and the F-4J

In 1974 the Navy let a contract with UAL to apply MSG-2 logic and procedures to the maintenance requirements for the F-4J aircraft at the Naval Air Rework Facility, North Island. The McDonnell Aircraft Company produced F-4J was at that time the high performance front line Navy fighter, and represented quite a change from any previous aircraft subjected to MSG-2 procedures. This effort was successful in the sense of accomplishing the task, although the new scheduled maintenance requirements program did not result in an immediate major reduction in maintenance costs. However, subsequent use of the analysis packages developed in this study allowed the newly MSG-2-procedures-trained engineering personnel at North Island to gather data and extend scheduled maintenance intervals for all levels of maintenance, resulting in considerable savings. As an example, phase

intervals were increased from 60 flight-hours to 80 and then 100 flight-hours, and Standard Depot Level Maintenance (SDLM) intervals for the F-4J/S were increased from 36 months to 42 and then 48 months.

3. The Analytical Maintenance Program

The new requirements packages for the F-4 were also of benefit in that they provided a much more logical and documented basis for justification of aircraft maintenance expenses to higher levels of authority. After the success of this project, the MSG-2 procedures were applied to most Navy aircraft by internal engineering personnel in connection with the Analytical Maintenance Program (AMP).

All of this procedural development resulted in a much more soundly based maintenance program for Naval aircraft. With the analysis packages developed using the MSG-2 based procedures, it became much easier for a new engineer or technician to become familiar with a system and/or component and its potential failure modes. This in turn improved the ability of engineering to monitor the performance of equipments in service and detect significant changes indicating a potential problem. It was also of great benefit in dealing with in-service problems, providing a better basis for rapidly dealing with the problems that arise with operating aircraft (temporary restrictions could be more realistic with a readily available breakdown of failure modes and the effects of failure modes).

AMP program analysis was conducted in accordance with procedures based on MSG-2. NAVAIR 00-25-400 [Ref. 6] was issued in 1975 and revised in 1978 to provide these procedures to internal Navy maintenance engineering personnel.

I. THE DEVELOPMENT OF RCM AND MSG-3

The AMP and MSG-2 procedures were found wanting in some areas and improved procedures were developed under the concept of Reliability-Centered Maintenance (RCM) leading to the publishing of revised procedures [Ref. 7] in 1981. Preceding this, United Airlines was commissioned by DOD to prepare a report [Ref. 1] laying out the history of aviation maintenance developments and giving rise to the new term of RCM. Reference 1 has a good executive summary of the development of RCM as an appendix.

On the commercial aviation side, the MSG-2 procedures were being refined further, resulting in the publishing of MSG-3 in 1980 [Ref. 8]. MSG-3 improved the analysis procedures for application to aircraft structure.

Nowlan and Heap [Ref. 1; pp. 388] gives a rather comprehensive statement on RCM philosophy used in thinking about safety and maintenance requirements. The statement is worth quoting in part:

".....Current thinking on the relationship between safety and scheduled maintenance can thus be summarized as follows:

-->> Failures are inevitable in complex equipment and can never be entirely prevented by scheduled maintenance.

-->> Reliability can usually be dissociated from safety by the design features of the equipment.

-->> A failure is critical only if loss of the function in question has a direct adverse effect on operating safety or if the failure mode that causes a loss of function also causes critical secondary damage. Because of this second condition, an item can have a critical failure mode even when the loss of its function is not critical.

-->> It is possible to design equipment so that very few of its failures or failure modes will be critical.

-->> In the few cases in which critical failure modes cannot be overcome by design, on-condition tasks and safe-life discard tasks can make the likelihood of a critical failure extremely remote.

-->> Scheduled overhaul has little or no effect on the reliability of complex items. Rework tasks directed at specific failure modes can reduce the frequency of failures resulting from those failure modes, but the residual failure rate will still represent an unacceptable risk. Consequently scheduled rework is not effective protection against critical failures.

-->> The technique of RCM analysis explicitly identifies those scheduled tasks which are essential either to prevent critical failures or to protect against the possible consequences of a hidden failure.

-->> Scheduled-maintenance tasks that do not relate to critical failures have no impact on operating safety. They do have an impact on operating costs, and their effectiveness must therefore be evaluated entirely in economic terms."

J. OTHER APPLICATIONS FOR RCM

It should be noted that DOD also looked into the application of RCM principles to other equipments. Navy ships and Army tanks are among the equipments that have been subjected to the analysis to insure that all scheduled maintenance requirements are justified. Grumman Aerospace Corporation conducted a DOD sponsored (Office of Assistant Secretary of Defense MRA&L) study in 1982 to determine the progress made in the application of RCM analysis procedures to all types of equipment. The report resulting from this study [Ref. 9] indicates that all services have had good success with the application of RCM logic to various types of equipment, and that expansion of the applications is continuing.

K. LOGISTIC SUPPORT AND OMB CIRCULAR NO. A-109

While these developments were taking place in the area of scheduled maintenance programs, the entire area of logistic support was being overhauled to develop a more unified and effective system. In 1970 the President appointed a commission to investigate the government acquisition system. The 1972 report of the Commission on Government Procurement recommended basic changes to improve the procurement process for major systems. As a result of this report, the Office of Management and Budget (OMB) published Circular No. A-109 [Ref. 10]. Circular A-109 addressed many areas in the

procurement process, and it will be examined in more detail later. The primary effect on maintenance programs for new acquisitions was a requirement to consider Life Cycle Costs (LCC) and to "Ensure appropriate trade-off among investment costs, ownership costs, schedules, and performance characteristics." [Ref., pp. 4; para. 7.c]. Part of the purpose of this effort was a system of logistics support that would start with the original conception of a new system and work interactively to provide the best possible system (in terms of performance and supportability) within whatever constraints (such as LCC) were applicable. The result of this process was the current system of Integrated Logistics Support (ILS) which will be examined in the next section.

III. CURRENT PRACTICES

A. INTRODUCTION TO SECTION III

The current system for developing the scheduled maintenance program for a new aircraft is complex and thorough. The scheduled maintenance requirements are developed as a subset of performing a Logistics Support Analysis (LSA) as required in the acquisition of a new weapon system. While performing the LSA, there are many iterations of tradeoff studies to optimize selected parameters while arriving at the best compromise between all of the competing elements. In this section the position of the maintenance requirements determination process is established in the overall scheme of things in the procurement of a new weapon system.

B. THE ACQUISITION PROCESS

The current set of procedures and regulations governing the acquisition of a new weapon system in the Department of Defense (DOD) is quite elaborate, and only major items will be summarized here. The procedures have been in a continuous state of flux since the Presidential Commission on Government Procurement submitted its report in 1972, and the Office of Management and Budget (OMB) issued Circular No. A-109 [Ref. 10] in 1976.

Circular No. A-109 directed all agencies, including DOD, to follow certain procedures in the acquisition process for a "major system." Major status for a system is assigned based on cost ceilings for the various acquisition phases. The prime requirement of A-109 was that the agency (such as DOD) should rely more heavily on competition to reduce costs in the acquisition process. Another requirement was that the agency should state the requirements for a new system in terms of a need, and not in terms of hardware; e.g., something is needed to counter a new threat, rather than we need a new aircraft of such and so dimensions and performance capabilities. The intent of this last requirement was to foster innovation on the part of the competitors from industry, and encourage open thinking in identifying solutions to the stated mission needs. A-109 also emphasized the need for independent cost estimating and establishing managerial systems to control the acquisition process without strangling it in paperwork. Consideration of Life Cycle Cost (LCC) was also stressed.

Current DOD instructions strongly reflect the guidance of A-109. The governing instructions for the acquisition of a major system, such as an aircraft, state emphatically that resources to achieve readiness shall be given equal weight with all other requirements, and that competition shall be used to minimize LCC [Ref. 11; pp. 2]. Department of Defense Instructions 5000.2 [Ref. 12] and 5000.39 [Ref. 13] are the

other basic acquisition process instructions. Figure 3 [Ref. 14; pp. 19, Figure 2] illustrates the overall system life cycle. The following is a breakout of the various phases in the acquisition process.

1. Initiation and the Concept Exploration Phase

The procurement of a new system normally starts with the identification of a mission need. The need might be based on a requirement to counter a new threat from a potential enemy, on the possibility of using new technology to gain a strategic advantage, or on the potential of accomplishing a needed expansion of existing capabilities in a cost beneficial way. In DOD the piece of paper used to start this process is a Justification for Major System New Start (JMSNS). The JMSNS is submitted with the Program Objectives Memorandum (POM) as part of the annual budget process in the Programming, Planning, and Budgeting System (PPBS), and is thereby reviewed by the Office of Secretary of Defense (OSD). If OSD approves the start of the new system it is included in the Program Decision Memorandum (PDM) which the Secretary of Defense (SoD) uses to submit the budget to OMB and the President.

The new program is authorized to begin once it is included in the PDM, but must await Presidential and Congressional approval by being funded in the approved budget before it officially starts. Once funds are received and a Program Manager is appointed to coordinate and guide the

PROJECT PHASES AND STAGES	TECHNOLOGICAL ADVANCEMENT	PROGRAM INITIATION PHASE: CONCEPTUAL STAGE	PROGRAM INITIATION PHASE: VALIDATION/ ADVANCED DEVELOPMENT STAGE	FULL SCALE DEVELOPMENT PHASE	PRODUCTION AND DEVELOPMENT PHASE: PRODUCTION STAGE	PRODUCTION AND DEVELOPMENT PHASE: DEPLOYMENT STAGE	OPERATIONAL PHASE	RETIREMENT AND DISPOSAL PHASE
PROJECT MILESTONES	0	I (OSARC)	II (OSARC)	III (OSARC)				
PROJECT DECISIONS	PROGRAM INITIATION	DEMONSTRATION AND VALIDATION	FULL SCALE DEVELOPMENT	PRODUCTION	DEPLOYMENT		PHASE OUT	
HARDWARE MODEL TYPES	EXPERIMENTAL, BREADBOARD MODELS	MOCK-UPS AND PROTOTYPES; ADVANCED DEVELOPMENT MODELS	BRASSBOARD; ENGINEERING DEVELOPMENT MODELS	PILOT PRODUCTION MODEL		PRODUCTION MODELS		

FIGURE 3. WEAPON SYSTEM LIFE CYCLE PHASES AND RELATED ACTIVITIES

acquisition, work begins on developing a concept, or concepts, to fulfill the need identified in the JMSNS. Concept exploration and definition is accomplished by asking for proposals on systems to meet the need expressed in the JMSNS from industry and/or government laboratories.

Review of the proposals received and selection of the competing concepts starts the acquisition process into the first acquisition process phase. Continuing system development into the next phase requires the approval of upper management. In DOD this approval comes from the Defense System Acquisition Review Committee (DSARC) which is chaired by the Defense Acquisition Executive (DAE, the Under Secretary of Defense for Research and Engineering) and is composed of other top level people from OSD, and the Chairman of the Joint Chiefs of Staff [Ref. 11; pp. 9-10] . This point in the acquisition process is labeled DSARC Milestone I. In prior years program initiation and the start of the Concept Exploration Phase was called Milestone 0, but this milestone terminology is no longer used. The approval process includes a reevaluation of the need for the system (Is the threat still valid, and is this the best way to counter it considering any interim developments?), and a review of potential costs for the alternatives. Affordability is a primary consideration. After successfully passing Milestone I, the next acquisition phase is Demonstration and Validation (DEM/VAL).

2. The Demonstration and Validation Phase

After the DSARC and SoD approve continuation of the system acquisition in Milestone I, the process progresses into the Demonstration and Validation Phase. In this phase the remaining competing concepts (the winners from Concept Exploration) are developed to the point of fully demonstrating feasibility, and the Logistic Support Analysis (LSA) process is considered, although normally not formally started. Design details are still very open to change, and the amount of effort required in this stage can vary considerably between the different competing concepts depending on the state of development of the technology involved. At the end of this phase, the system must pass DSARC Milestone II to proceed on to the next phase, Full Scale Development (FSD). At the end of Dem/Val, target values are set for reliability and maintainability performance, as well as for performance goals on other parameters.

3. The Full Scale Development Phase

At DSARC Milestone II the need for the system is again critically evaluated against current and projected developments in the environment. Progress in relation to program schedule and budget projections is also subjected to critical review. The approval for continuation of the program comes from the SoD in conjunction with the DSARC.

After Milestone II the further acquisition cycle approval of the system is normally transferred to the head of the Department (e.g., Secretary of the Navy) as long as the program stays within guidelines for cost and schedule. During FSD the formal design of the system starts. Prototypes are built and (for aircraft programs) competitive fly-offs are held between the competing designs (two or more).

At the start of this phase (and in some cases in the preceding phase) the LSA begins with the development of the Maintenance Concept. It continues in an interactive iterative mode with the design process to weigh each of the major Integrated Logistics Support (ILS) elements (Maintenance Planning, Supply Support, Personnel and Training, Testing and Support Equipment, Facilities, Transportation and Handling, Data, and Software [Ref. 2: pp. 11]) and insure that a balanced compromise between performance, reliability, maintainability, supportability, and cost is reached in the resultant system design. During this iterative process LCC analysis plays a major role in the working out of compromises in the design between the various logistic and performance alternatives. Target values for Reliability, Maintainability, and other support related factors are set at this time if not previously. The LSA process will be examined in detail in the next section.

After design and manufacture of the prototype system, a fly-off is held between the competitors and the final DSARC Milestone is entered. For DSARC Milestone III the program again goes through a critical review to verify that the mission need is still current and valid, that the LCC estimates are within the bounds of affordability and budget projections, and that the schedule is compatible with the Initial Operational Commitment (IOC) date. The IOC date is scheduled after DSARC Milestone I as a target for fleet introduction. This date must be closely coordinated with the scheduling of all of the logistic support requirements (trained personnel, spare parts, peculiar support equipment, etc., should be on site when the new aircraft reaches the fleet). With the approval of the DSARC and SEC NAV or SoD, the program passes Milestone III and is ready to proceed to either pilot production or full-scale production assuming funding is obtained from the Congress. In some cases the DSARC leaves the Milestone III review to the designated Acquisition Authority (e.g., SEC NAV), although this is less likely with a major aircraft procurement.

4. The Production and Deployment Phase

The next phase in the acquisition process is Production and Deployment. In this phase production prototypes are built and full scale production starts. The production prototype aircraft is tested and evaluated to verify fleet acceptability and adequate performance either

concurrently with the initial production effort, or prior to it (normally concurrently with a less than capacity start of production). Producibility is also evaluated here and is the FSD phase to minimize acquisition costs.

Following successful testing and evaluation, the aircraft is introduced to the fleet where all (hopefully at least most) of the logistic support elements are in place to insure a smooth start up of the system operation (often work around procedures are required to fill in until all of the support items are ready).

5. Phase Out and Retirement

The final phase of the acquisition process is Phase-Out and Retirement as the system goes out of service. This phase can take several forms, but it is not relevant to operational maintenance requirements and will, therefore, not be examined further.

C. LOGISTIC SUPPORT ANALYSIS (LSA)

LSA is a subset of Integrated Logistic Support (ILS) and is initiated with the beginning of the Full Scale Development (FSD) phase of the acquisition process. LSA is performed in accordance with MIL-STD-1388-1A [Ref. 15]. LSA looks at the eight major ILS elements (Maintenance Planning, Supply Support, Personnel and Training, Test and Support Equipment, Transportation and Handling, Facilities, Data, and Software) and attempts to achieve a balance between the various

logistic elements and system performance parameters (speed, range, etc.) at an affordable cost. The common factor in the compromise process of tradeoff analysis is Life Cycle Cost (LCC). Each logistic element is examined for an optimum performance level and then the sensitivity of each element to the others is examined. This is all done in conjunction with the design group in an iterative fashion with LCC a major factor in each tradeoff analysis. Figure 4 [Ref. 14; pp. 12, Figure 1] illustrates the integrated LSA and maintenance planning process.

1. The Maintenance Concept

LSA starts with the development of the Maintenance Concept. The initial Maintenance Concept is often subject to numerous changes as the design process progresses, but the initial cut provides guidance for the beginning portions of the LSA. The initial Maintenance Concept identifies what levels of maintenance will perform what functions on the system. Such things as skill levels required for personnel, and numbers of personnel at each maintenance level (the three levels of maintenance for the Navy are Organizational (squadron), Intermediate, and Depot) are directly resultant from this decision. Other factors that are impacted by the Maintenance Concept are kind and amount of test and support equipment required at each level, number of spares to be stocked for each level, and so on. Each of the major ILS elements is impacted by this decision. All of the data

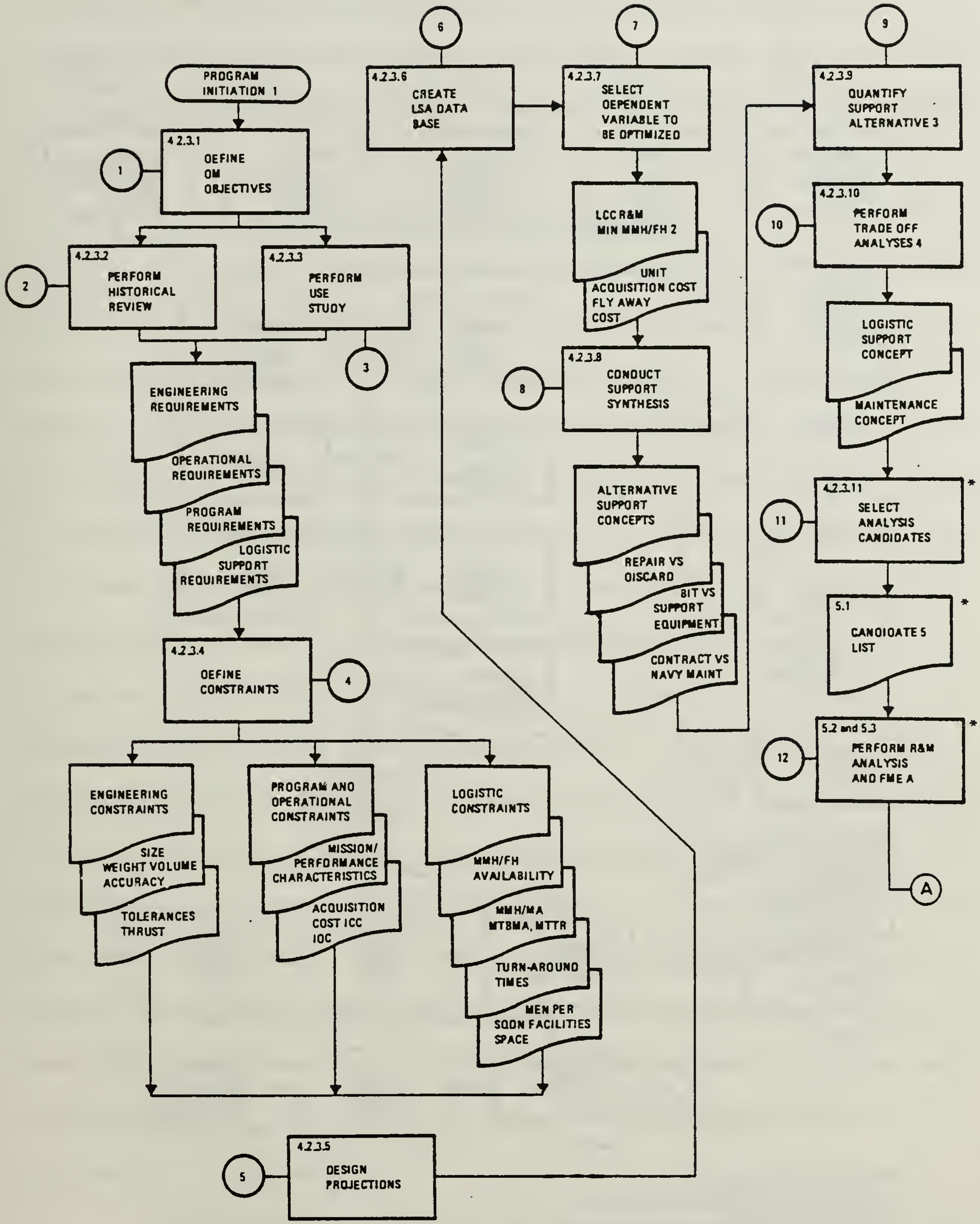
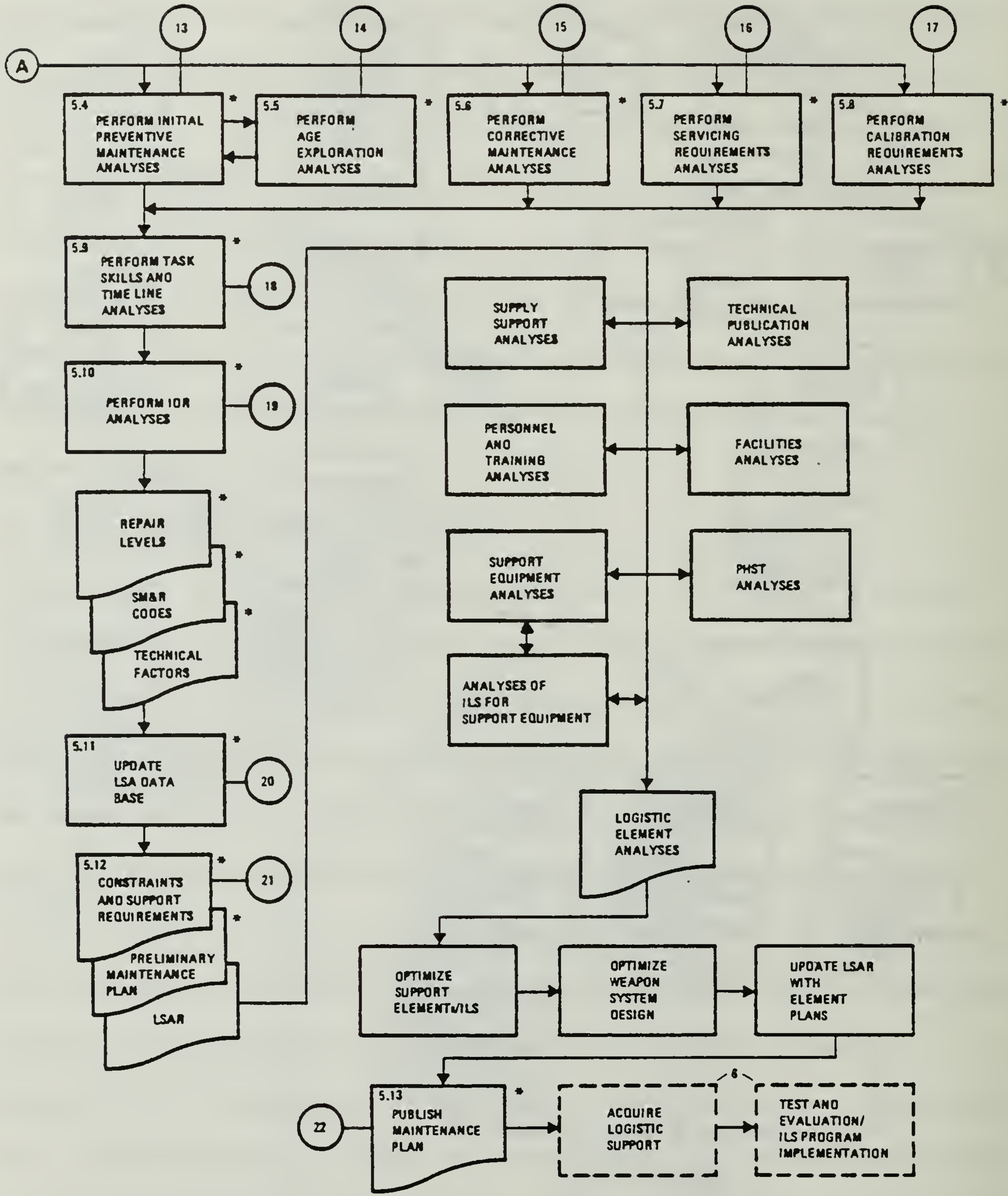


FIGURE 4. INTEGRATED LSA AND MAINTENANCE PLANNING PROCESS (SHEET 1 OF 2)



NOTES:
1. FEEDBACK LOOPS ARE NOT SHOWN
2. ONLY ONE DEPENDENT VARIABLE OBJECTIVE FUNCTION CAN BE OPTIMIZED AT A TIME
3. SUPPORT ELEMENT SOLUTIONS MUST BE DEVELOPED
4. TECHNIQUES EMPLOYED INCLUDE MATRIX ANALYSIS, PARAMETRIC ANALYSIS' SIMULATION' SESITIVITY ANALYSIS AND LCC
5. BASED ON COST, COMPLEXITY AND SUPPORT DEMAND INCLUDES SE TRAINING EQUIPMENT AND GFE
6. PART OF ILS MANAGEMENT PROCESS
* MAINTENANCE PLANNING AND ANALYSIS (MPA) PROCESS

FIGURE 4. INTEGRATED LSA AND MAINTENANCE PLANNING PROCESS (SHEET 2 OF 2)

developed during the LSA go into the Logistic Support Analysis Record (LSAR) which provides a common data base for everyone involved in the process and helps to reduce confusion.

2. Preparation of Maintenance Plans

Following the development of the initial Maintenance Concept the LSA process proceeds to preparation of Maintenance Plans per MIL-STD-2080A [Ref. 14], supported by a Failure Mode, Effects and Criticality Analysis (FME&CA) per MIL-STD-1629A [Ref. 16]. NAVAIR 00-25-401 [Ref. 17] provides a guide for maintenance engineers applying these procedures to Naval aircraft. This process interacts with the design process iteratively through numerous trade-off and alternatives studies to minimize LCC without overly compromising system design parameters. The iterations between design and LSA work toward the target reliability and maintainability values. Maintenance plans are prepared for individual systems, and/or subsystems, and/or components as the design matures. The initial efforts look at the top levels of aircraft systems, and as the design matures the analysis continues down to the component level. During each stage there is interaction between the designer and the maintenance analyst.

Preparation of maintenance plans includes an analysis of Preventive (scheduled) Maintenance and Age Exploration requirements per MIL-HDBK-266(AS) [Ref. 7], Corrective

(unscheduled) Maintenance requirements, Servicing requirements, and Calibration. Each analysis is broken down into a Task and Skills Analysis which includes: maintenance tasks and resources, personnel requirements, training requirements, support equipment requirements, facilities requirements, and a Time Line Analysis (Which tasks can be accomplished concurrently, and which will require separate access with the associated additional down time?).

Maintenance plans also include Level of Repair (LOR) analysis per MIL-STD-1390 [Ref. 18] to identify cost-effective level of repair and discard decisions. The LOR decisions are reflected in the assigned SM&R (Source, Maintainability, and Recovery) codes which are eventually used in service by maintenance personnel to determine what is to be done with a defective part. The SM&R code indicates level of maintenance, level of condemnation (which level decides whether a repairable component is repairable), and whether the item is a repairable or a discard.

The Preventive Maintenance and Age Exploration requirements developed as subsets of the maintenance plans use the same data base, the LSAR, as a starting point and then add to this data base.

Concurrently with the preparation of maintenance plans the LSA looks at all of the major ILS elements to achieve a balanced system design from performance, reliability, maintainability, supportability, and LCC

standpoints. Since the elements are interrelated, each change to one must be evaluated for impact on the others. This cycle is repeated many times as the design matures toward the target values for performance, reliability, and maintainability identified at the start of the FSD phase.

IV. RCM AND SCHEDULED MAINTENANCE REQUIREMENTS

A. RELIABILITY-CENTERED MAINTENANCE

Reliability-Centered Maintenance (RCM) is the logical analysis technique used to determine scheduled or preventive maintenance requirements. MIL-HDBK-266 (AS) [Ref. 7] provides procedures for application of RCM logic to Navy aircraft. RCM is an outgrowth or further development of MSG-2 and uses inputs from the maintenance plans prepared per MIL-STD-2080A to determine scheduled (preventive) maintenance requirements and Age Exploration requirements. These requirements result from a rigorous analysis logic which has been refined to a state of giving consistent results independent of the analyst. The objective of the logic is to provide a set of fully justified requirements which insure that the equipment being maintained achieves its inherent design reliability without wasting resources on unnecessary tasks. This aim is accomplished via the specified preventive maintenance tasks (at this stage servicing tasks are generally included with the preventive tasks), in conjunction with Age Exploration tasks designed to provide real data on those components and systems which were assigned scheduled tasks through the default side of the logic diagram to insure a conservative or safe maintenance program. During the design phase there is steady communication between the

maintenance analyst and the designer to modify the design as necessary to eliminate overly expensive or untimely maintenance requirements. As data are obtained from service usage via Age Exploration, the default tasks are either verified as valid, or can be eliminated or adjusted to longer intervals based on their service performance.

B. STARTING AN RCM ANALYSIS

The RCM analysis starts with a determination of the significance of major systems, subsystems, and components from a safety and maintenance standpoint. Once items are classified as significant, a review of available data on the item is conducted. This includes design data, test data, and any service history data on the components and/or system in question or on similar components and/or systems. These data are used in conjunction with the maintenance plans and the FME&CA to start the investigation of preventive maintenance requirements. Figure 5 [Ref. 7; pp. 15, Figure 2] illustrates the overall RCM analysis process. The key factor in the determination of maintenance requirements is the failure consequences for the component or system. If the failure of an item does not have any safety or economic consequences, it does not warrant a scheduled task. If failures occur too frequently (low reliability), redesign is indicated. If the failure of the item has safety implications and a scheduled task will detect impending

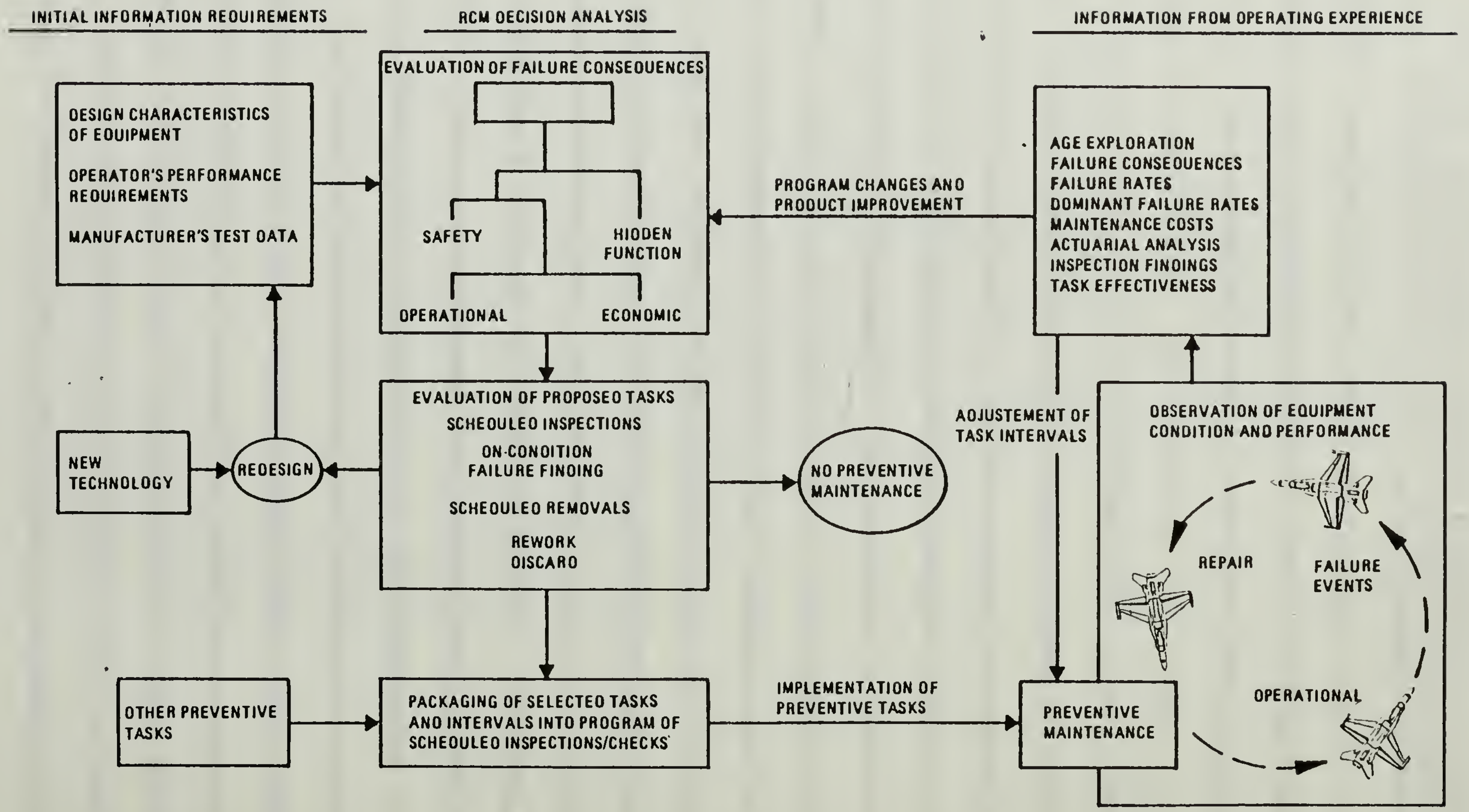


FIGURE 5. RCM ANALYSIS PROCESS

failure, then a scheduled task is in order, or redesign of the equipment is called for to eliminate the need for scheduled maintenance. If a scheduled task cannot be used to detect impending failure where there are safety consequences, then redesign is mandatory. If the failure has economic consequences, it falls into the same category as the safety item although redesign is desirable rather than mandatory depending on the magnitude of the economic implications of failure.

C. HIDDEN FUNCTIONS

The other factor that requires a scheduled task is the hidden function. If the failure of an item is not evident to the operating crew in the normal performance of their duties, a scheduled task or redesign is required. Depending upon the degree of redundancy in the system, tasks required to monitor hidden functions may have either long or short intervals.

D. THE RCM LOGIC

Figure 6 [Ref. 7; pp. 17-18, Figure 3] illustrates the RCM logic. An analyst starts at the top of the diagram and works downward depending on the answers to each of the questions. As noted earlier the system is much more powerful when the design is still fluid and can be readily modified to eliminate an expensive or unmaintainable feature.

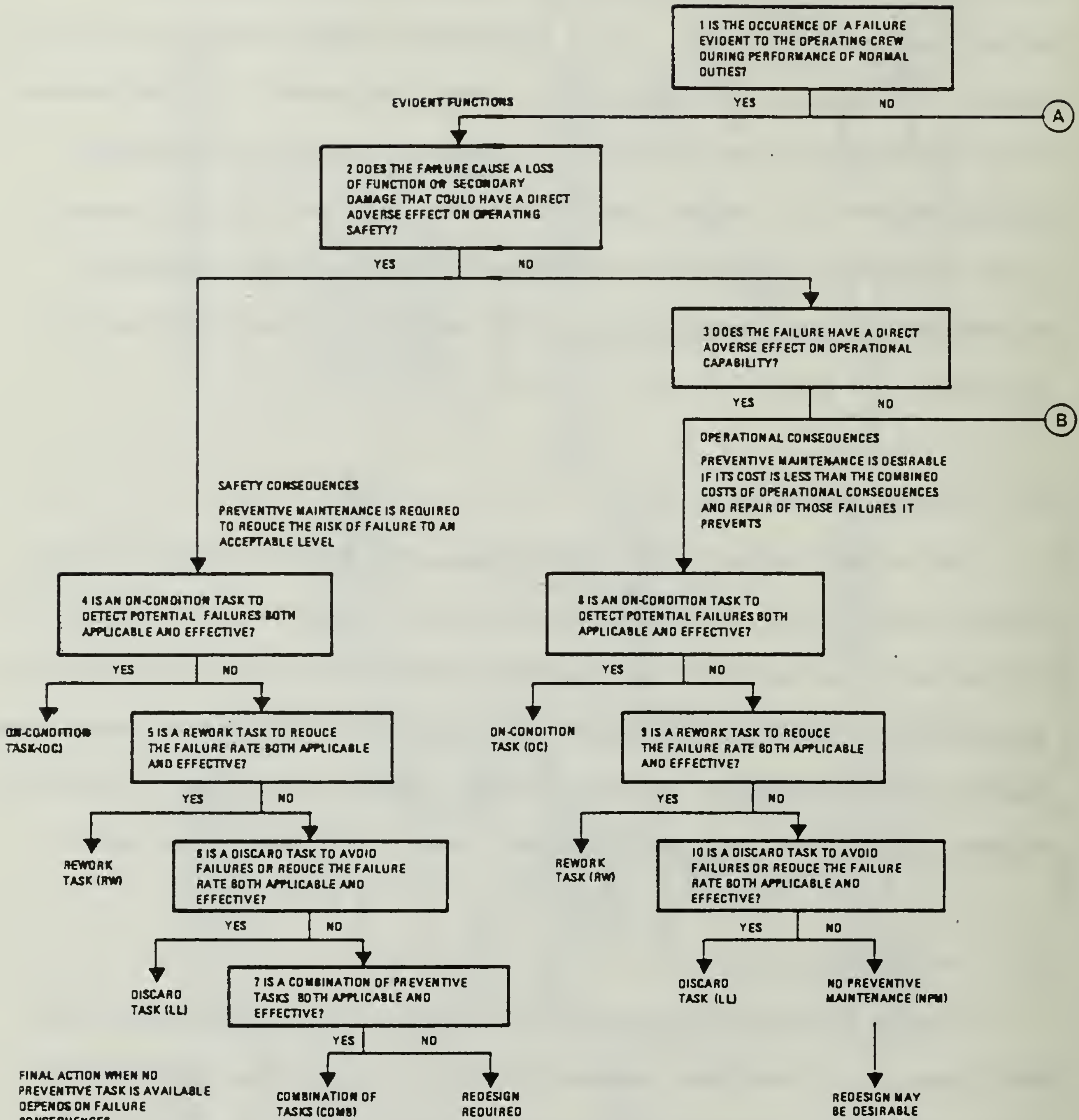


FIGURE 6. RCM DECISION DIAGRAM (SHEET 1 OF 2)

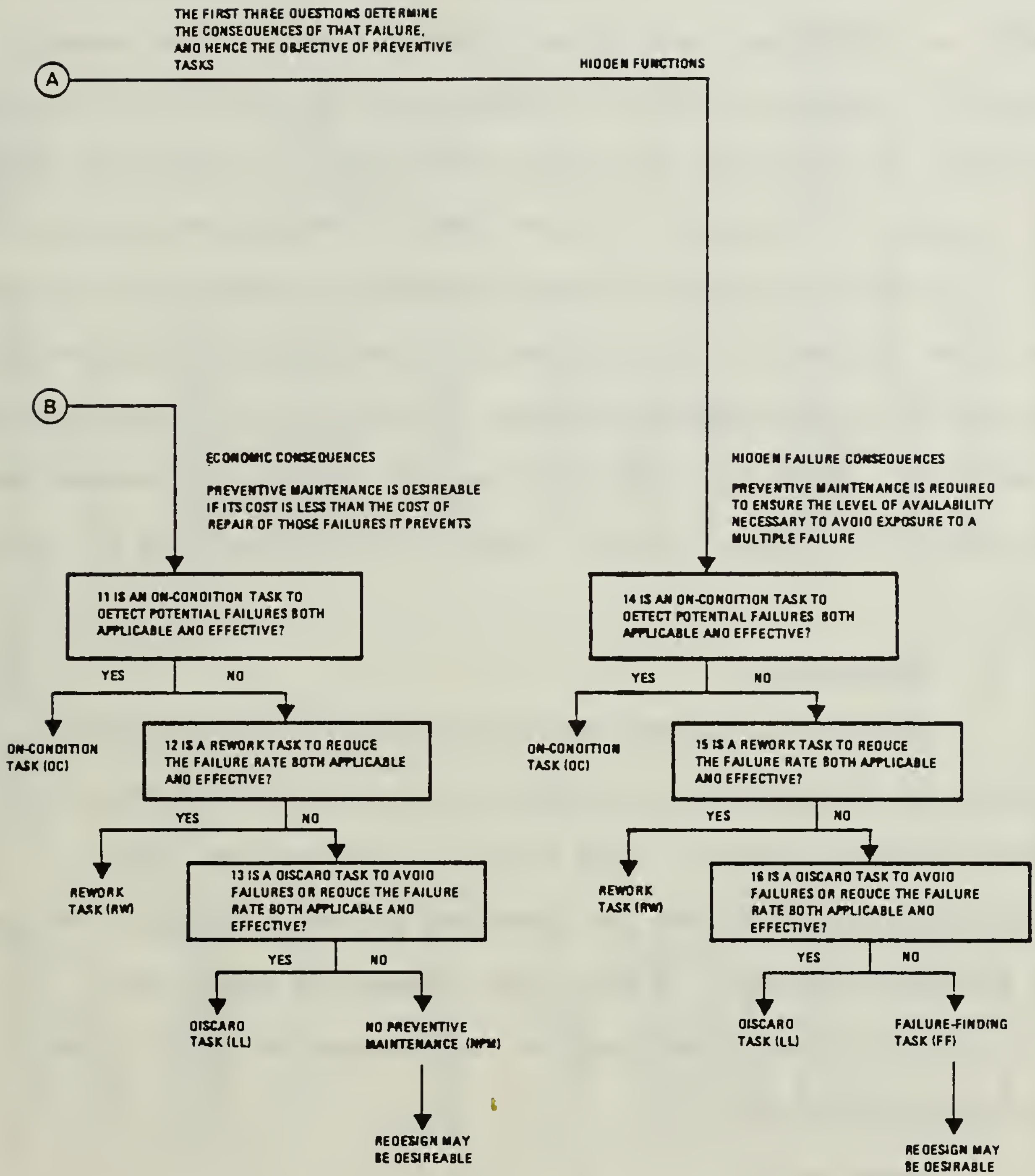


FIGURE 6. RCM DECISION DIAGRAM (SHEET 2 OF 2)

For each of the questions a conservative default answer is required if data are inadequate to allow a knowledgeable response. Because of this feature of the logic process, a number of scheduled maintenance tasks result from default answers. However, default answers are subject to critical scrutiny once further data are available from service usage via the Age Exploration Program (AEP), and these tasks will fall out of the program if data become available showing that they are not valid. The default answer feature insures that the overall maintenance program is conservative from a safety standpoint. Figure 7 [Ref. 7; pp. 19, Figure 4] summarizes the default decision logic. The primary questions in Figure 6 are:

1. <u>Question 1</u>

Question 1 starts the flow through the decision diagram by pointing the analyst to either the evident or hidden function side. This answer, and most of the succeeding answers, can be reversed by modifications during the design process. In this way scheduled tasks are eliminated through redesign of the system if it is cost effective to do so.

2. <u>Question 2</u>

The answer to Question 2 puts the analyst on the safety consequences path, or the operational or economic consequences paths.

DECISION QUESTION	DEFAULT ANSWER TO BE USED IN CASE OF UNCERTAINTY	STAGE AT WHICH QUESTION CAN BE ANSWERED		POSSIBLE ADVERSE CONSEQUENCES OF DEFAULT DECISION	DEFAULT CONSEQUENCES ELIMINATED WITH SUBSEQUENT OPERATING INFORMATION
		INITIAL PROGRAM (WITH DEFAULT)	ONGOING PROGRAM (OPERATING DATA)		
IDENTIFICATION OF SIGNIFICANT ITEMS Is the item clearly nonsignificant?	No: Classify item as significant.	X	X	Unnecessary analysis.	No
EVALUATION OF FAILURE CONSEQUENCES Is the occurrence of a failure evident to the operating crew during the performance of normal duties?	No (except for critical secondary damage); classify function as hidden.	X	X	Unnecessary inspections that are not cost effective.	Yes
Does the failure cause a loss of function or secondary damage that could have direct adverse effect on operating safety?	Yes: Classify consequences as critical.	X	X	Unnecessary redesign or preventive maintenance that is not cost effective.	No for redesign; yes for preventive maintenance.
Does the failure have a direct adverse effect on the operational capability?	Yes: Classify consequences as operational.	X	X	Preventive maintenance that is not cost effective.	Yes
EVALUATION OF PROPOSED TASKS Is an on-condition task to detect potential failures applicable.	Yes: Include on-condition tasks in program.	X	X	Preventive maintenance that is not cost effective.	Yes
If an on-condition task is applicable, is it effective?	Yes: Assign inspection intervals short enough to make task effective.	X	X	Preventive maintenance that is not cost effective.	Yes
Is a rework task to reduce the failure rate applicable?	No (unless there are real and applicable data); assign item to no preventive maintenance.	---	---	Delay in exploiting opportunity to reduce costs.	Yes
If a rework task is applicable, is it effective?	No (unless there are real and applicable data); assign item to no preventive maintenance.	---	X	Unnecessary redesign (safety) or delay in exploiting opportunity to reduce costs.	No for redesign; yes for preventive maintenance.
Is discard task to avoid failures or reduce the failure rate applicable?	No (except for safe life items): assign item to no preventive maintenance.	X (safe life only)	X (economic life)	Delay in exploiting opportunity to reduce costs.	Yes
If a discard task is applicable, is it effective?	No (except for safe life items): assign item to no preventive maintenance.	X (safe life only)	X (economic life)	Delay in exploiting opportunity to reduce costs.	Yes

The default answers to be used in developing an initial preventive maintenance program in the absence of data from actual operating experience.

FIGURE 7. DEFAULT DECISION LOGIC CHART

3. Question 3

Question 3 directs the analyst to either Question 8 and the operational consequences path, or Question 11 and the economic consequences path.

4. Question 14

The analyst arrives at Question 14 after a hidden function answer to Question 1. The questions and answers on this path are particularly sensitive to design changes.

The ease with which the questions asked on each of these paths can lead to economic analysis and system redesign should be noted. Working with the system designer the maintenance engineer can preclude some unnecessary and expensive maintenance requirements by suggesting simple changes to the design. More complicated changes to the design may require a thorough analysis of all of the financial (LCC) and operational implications. However, even if the design isn't changed as a result of the maintenance engineers input, a record of the perceived problem is retained and when more data become available the decision may be reversed or substantiated. The record should preclude the question being reinvented periodically throughout the life of the program causing resources to be wasted researching again all of the factors involved.

E. PREVENTIVE MAINTENANCE TASKS

Preventive maintenance tasks resulting from the RCM analysis can be one of two basic types: scheduled inspection, or scheduled removal.

1. Scheduled Inspections

Scheduled inspections may be applicable to any maintenance level, and are aimed at detecting impending failures (on-condition), or failures (failure finding). The design may or may not lend itself to the detection of impending failure or wear. Depending upon this, and the consequence of failure, a redesign may be either desirable or required.

2. Scheduled Removals

Scheduled removals are of two types: removal for rework (scheduled rework), or for discard (scheduled discard). This is again a result of the design and is usually driven by the cost of the item and its reliability. High reliability inexpensive items are usually discarded. Lower reliability more expensive items may be repaired.

Figure 8 [Obtained from VSE Corporation] illustrates the decision process used in analyzing a component or system to determine scheduled maintenance task requirements. The VSE diagram directly addresses the assessment of risk in the mainteance analysis process, questions the continuing maintenance of an item which is not mission essential (such as a flight data recorder), and provides a pathway to the

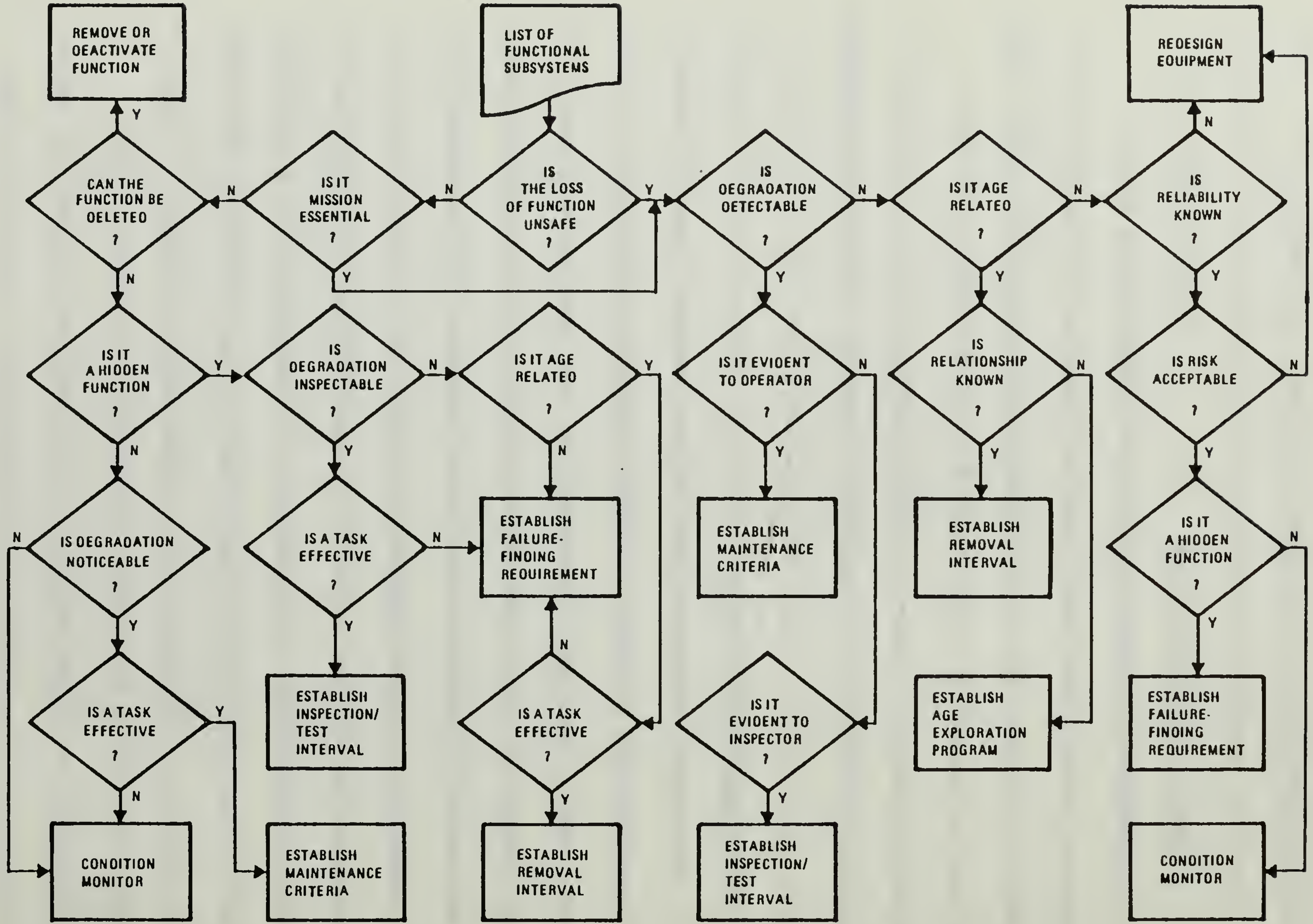


FIGURE 8. MAINTENANCE TASK DECISION DIAGRAM FOR SUBSYSTEMS AND EQUIPMENT

establishment of an Age Exploration Program. Figure 9 [Ref. 7; pp. 21, Figure 5] summarizes the preventive tasks and their applicability.

F. THE MAINTENANCE PROGRAM

Once all significant items are subjected to the analysis a number of scheduled maintenance tasks result. The final job of the analyst for initial maintenance program determination is to join all of these tasks into groups in a composite program. The groupings are determined based on the level of maintenance required to perform the task, and on the interval determined for the task. Tasks ultimately scheduled for a given inspection are grouped according to similar intervals. A task determined to have an optimum 100 flight-hour (FH) interval, and a task determined to have an optimum 80 FH interval might be grouped together in an 80 FH phase inspection (an inspection performed every 80 FH) with a task having a 500 flight-hour optimum interval included in every sixth phase (there are six phases in the cycle which starts over again each 480 FH in this example) The resultant program consists of: organizational level phase inspections at some flight-hour interval; daily and special inspections at calendar intervals; removal/discard tasks at flight-hour or other accumulation of cyclic events (e.g., arrestments) or calendar intervals; and depot level tasks scheduled for some SDLM (Standard Depot Level Maintenance) interval, or a service interval separate from SDLM.

FAILURE CONSEQUENCES

TASK	SAFETY	OPERATIONAL	ECONOMIC	HIDDEN FAILURE
Effectiveness				
All	Must reduce risk of failure to acceptable level.	Must be cost effective; cost of scheduled maintenance must be less than combined cost of loss of operation and repair.	Must be cost effective; cost of scheduled maintenance must be less than cost of repair.	Insure level of availability to reduce risk of multiple failure to acceptable level.
Applicability				
On Condition	1. Possible to detect reduced failure resistance. 2. Possible to define potential failure condition that can be detected by an explicit task. 3. Consistent age betwen potential failure and functional failure.	Same	Same	Same
Scheduled Rework	1. Identify age with rapid increase in conditional probability of failure. 2. Large percentage must survive to this age. 3. Possible to restore original failure resistance by rework.	Same	Same	Same
Scheduled Discard	1. Must be critical failure. 2. Specified age limit below which no failures occur.	1. Failure has major operational consequences. 2. Identify age with rapid increase in conditional probability of failure. 3. Large portion must survive to this age.	Same as operational	1. Must be critical multiple failure. 2. Specified age limit below which no failure occur.
Failure Finding	------------	------------	------------	1. Must be a hidden function. 2. No other task is applicable or effective.

FIGURE 9. APPLICABILITY AND EFFECTIVENESS CRITERIA SUMMARY

AEP tasks are included in the maintenance program , and the data from these tasks are used to modify the maintenance program as service history is accumulated. AEP tasks normally carry a requirement to report the results of the task, especially if a defect is found. Initially Age Exploration will delete or modify some of the default tasks, but in the mature program it will serve to monitor most of the significant maintenance items on a periodic basis to substantiate the original analysis and provide a basis for modifying the program as necessary to promote a safe and economically sound program.

In the case of more modern designs, SDLM may be eliminated and replaced by a statistical sampling program tied to Age Exploration looking at relatively small numbers of aircraft to maintain confidence in the design. Eliminating SDLM saves large amounts of funds required for the depot visit of all aircraft of a type/model/series, reduces the number of aircraft required for the depot maintenance pipeline, and reduces the number of problems created by performing in-depth maintenance (the infant mortality curve).

V. THE F/A-18 MAINTENANCE PROGRAM

A. THE GENERAL PROGRAM

The maintenance program developed for the Navy's newest fighter/attack aircraft is based on RCM and the instructions noted in the preceding section, although program initiation predated the latest revisions of these instructions. The F/A-18 was designed from the ground up for high reliability and reduced maintenance. Early results from the operation of the aircraft indicate that it is going to meet design objectives in this area.

Table I contains maintenance data for the F/A-18, the F-14, and the F-4. All of these Navy fighter aircraft have been subjected to RCM type analyses to optimize their maintenance programs, and the differences in maintenance costs for the F/A-18 are illustrative of the benefits of including front end logistics analysis in the design process.

The F-4 was designed in the late 1950s and was initially delivered to the fleet in 1961. Later models (F-4J/S) were redesigned in the mid 1960s to reduce or eliminate some of the more troublesome features of the original design, but the design is essentially more than twenty years old. Supportability requirements did not receive equal consideration to performance parameters when the F-4 was

designed as would be required today, and the high maintenance man-hour per flight-hour (MMH/FH) values reflect this.

The F-14 was designed in the mid-to-late 1960s and entered service about 1972 making the design over ten years old. Supportability was not a major factor in the design of the F-14, and it is a more complex aircraft than the F-4.

TABLE I

AVERAGE MAINTENANCE MAN-HOURS PER FLIGHT-HOUR FOR CALENDAR YEAR 1983

	F-4S	F-14	F/A-18
Organizational Scheduled	19.2	30.6	14.8
Organizational Unscheduled	19.0	19.6	9.1
Intermediate	13.4	11.7	4.3
TOTALS	51.6	61.9	28.2

Source: NAMSO Report 4790.A7936.1, Aviation Information Digest (AID), January 1984

The F/A-18 maintainability values indicated in Table I should improve as more aircraft enter service, and the program reaches maturity. The comparative numbers show clearly the advantages of front end investment in reliability, maintainability, and supportability considerations when designing a new system. The better maintainability values shown for the F/A-18 are of course

partially a result of improvements in technology since the design and manufacture of the older aircraft; however, it is significant that this does not appear to be the case when comparing the F-14 and F-4 where there was an advance in technology, but not as much attention to supportability and maintainability during the design process.

B. ORGANIZATIONAL MAINTENANCE

The organizational (O level) maintenance requirements for the F/A-18 are similar to those for the older designs although less demanding. Partially as a result of the design of the weapon system the number of personnel required in an F/A-18 squadron of twelve aircraft is 231, instead of the 273 required for an F-4 squadron, and 256 required for the F-14. Table II breaks out these requirements in more detail. Intermediate level maintenance is called I level. It should be noted that the F/A-18 is a single seat aircraft as opposed to the two seats in the F-4 and F-14, and this is partially responsible for the lower number of officers in the F/A-18 squadron.

1. Built-in Test Capability

Most of the F/A-18 systems are designed with built-in test (BIT) capability to reduce the amount of test and support equipment required, and to lower the skill levels required for squadron (operational level) maintenance personnel. Ready access for maintenance also received more

consideration than in previous designs reducing corrective maintenance and turn-around times.

TABLE II

PERSONNEL REQUIREMENTS

	F-4	F-14	F/A-18
Officers	38	34	22
Enlisted O Level	181	172	164
Enlisted I Level	27	25	22
Enlisted TDA	27	25	23
TOTALS	273	256	231

Source: Commander, Naval Air Force Pacific Staff

2. Accessibility Considerations

Good access addresses the ease of reaching a component for maintenance with little or no disassembly. High maintainability targets drive the design team to work hard for good access to meet repair time and component removal and replacement time goals. The reduction in size of most electronic components possible with more advanced technology can be of great help in designing for access. Another advanced technology factor in the ability to design for better accessibility is the use of Computer Aided Design (CAD). CAD is the application of computer graphics to the

design process. Two and three dimensional graphics were used in the design of the F/A-18. Northrop engineers have estimated that World War II vintage aircraft were designed to about 30 percent density (ratio of filled to empty space within the airframe), F-4 vintage aircraft to about 45 percent density, and the F/A-18 to about 70 percent density. The improvement is a result of using CAD in the design of the F/A-18. However, one should realize that although CAD allows the designer to improve accessibility, it also allows him to pack everything more tightly than was possible previously, and if accessibility isn't given primary consideration a truly unmaintainable installation can result.

Organizational level maintenance in many cases consists of initiating BIT procedures and changing the boxes indicated. These boxes are called Line Replaceable Units (LRUs). The removed LRUs are forwarded to the intermediate level in most cases, where automatic test equipment identifies a bad component needing replacement. Some more complex items are returned to depot level (the manufacturer under a warranty or Repair of Repairables (ROR) program in many cases) for maintenance where more sophisticated (and more expensive) test equipment and more highly skilled craftsmen can be concentrated more economically (higher utilization rates are possible in a centralized system). Part of the maintenance concept for the aircraft systems was labeled Directly Deployable Maintenance which aimed to keep

as many LRUs as possible repairable at the O and I levels. This in turn reduces turn-around-time for repairs, reduces the quantity of spare assemblies needed in close proximity, and facilitates long deployments when necessary. In some cases this was not feasible in the F/A-18 design due to the cost of the required test equipment (extremely expensive test gear can only be purchased for a central repair site such as a depot).

The goal of the design effort was an aircraft that would be much more reliable and easy to maintain than its predecessors, and it appears that this will be the case. As in the past, organizational scheduled maintenance requirements will be published in the NAVAIR -6 series of Maintenance Requirements Card (MRC) decks.

The Age Exploration Program (AEP) will monitor the results of organizational maintenance to provide a basis for any needed modifications to the requirements. Particular attention will be paid to the default tasks mentioned in paragraph IV.D above.

C. DEPOT MAINTENANCE (AGE EXPLORATION PROGRAM)

The depot maintenance program for the F/A-18 is presently called the Age Exploration Program (AEP) (Depot). This title is appropriate since it is anticipated that there will be no SDLM for the F/A-18 although this will not be finally decided until after the first aircraft samples are inspected and

results analyzed. There are at present no scheduled depot tasks in the program applicable to all aircraft. Depot requirements will be published in an annual Maintenance Requirements Review Board (MRRB) Brochure [Ref. 19], and statistically significant samples of fleet leading aircraft in particular categories (flight-hours, catapults, low free-board carrier service, etc.) will be selected for study each year. It is quite possible that several different samples of different sizes would overlap at one time in a given year as items of particular concern are investigated. It is estimated that 6,500 man-hours (MHs) will be required for each of the first AEP (Depot) aircraft. Table III provides SDLM NORM values (average MHs planned for a SDLM visit) for the F-4 and F-14. These NORMS can be compared to the 6,500 MH scheduled for AEP.

In looking at Table III one should consider that the 20,410 man-hour F-14 SDLM converts to $1,020,500 for each aircraft at a realistic $50/hour composite depot labor rate. With a fleet of say 440 aircraft on a 44-month interval, this results in $122,460,000 for depot maintenance each year. The $122,460,000 figure can be roughly compared to the $9,100,000 cost of inspecting 28 AEP aircraft per year at 6,500 man-hours each for a fleet of 1,300 aircraft. Of course when problems are discovered during AEP inspection or by some other means (fatigue testing, squadron maintenance, modification lines, crash damage investigation, strain gauge

data, etc.) additional expense will be added to the $9,100,000 figure [Ref. 20].

The formal decision on whether the F/A-18 will have a regularly scheduled SDLM has not been made as yet. This decision will be officially made after the first 48 aircraft are inspected via the AEP (Depot) [Ref. 20]. The initial sample size will be 28 aircraft giving a 95 percent confidence level of finding a defect in the sample if it is present in 10 percent or more of the fleet [Ref. 20].

TABLE III

DEPOT REWORK REQUIREMENTS

	F-4	F-14	F/A-18
Tour Length (Months)*	48	44	N/A
NORM (Man-Hours)**	13,875	20,410	N/A

Source: * OPNAVINST 3110.11P
** NARF North Island Production Planning Department

1. Sample Sizes

A sampling program apparently places more confidence in the original design than previously was considered possible or advisable. The percentage differences in confidence of finding a defect in either sampling or wholesale SDLM need not be large, however, if the size of the

statistical sample is carefully chosen. The large sample sizes used in previous programs (essentially 100 percent of the population) were usually based on requirements to look at certain structural items on a periodic basis with depot skill level personnel. Current thinking [Ref. 21; Appendix B; and Ref. 22; pp. 13] indicates that samples of 22 aircraft per year will be adequate to give a 90 percent confidence level of finding a defect present in the sample if the defective condition exists in ten percent or more of fleet aircraft. As noted above the initial sample size will be 28, giving a 95 percent confidence level of finding a defect present in ten percent of the fleet. These confidence levels assume no inspection errors, which is highly optimistic. In a major U.S. Air Force study the probability of finding small cracks (less than 0.5 inch in length) was found to be as low as 50 percent [Ref. 23; pp. 12-2]. However, this information is balanced by the fact that crack detection capabilities were considered in the design and analysis of structural components for the F/A-18 which was not done with older aircraft. F/A-18 structural components were designed for four fatigue lifetimes (24,000 spectrum hours) assuming the presence of an 0.010 inch initial flaw (crack) [Ref. 22; pp. A1-1]. Critical structural components, those components whose failures by themselves produce a safety of flight situation, were subject to additional analysis to identify where, when, and how to inspect, and what to look for [Ref.

24; pp. 8]. These requirements give a greater degree of confidence in the design than was previously possible.

2. <u>In Support of Statistical Sampling</u>

More exacting design and analysis techniques coupled with more realistic testing techniques (The original F-4 fatigue test program did not include negative or asymmetric loads, and landing loads were included in a separate test program.) have greatly reduced or eliminated the need for looking at all aircraft. In addition, the F/A-18 has built-in strain gauges to give a much more accurate picture of aircraft fatigue life usage than was possible with the counting accelerometer used on previous aircraft.

Another modern development helping the F/A-18 is the use of the ACMR (Air Combat Maneuvering Range). The ACMR is a training device wherein pilots fly their aircraft against simulated enemy aircraft within the confines of an expansive range. A version of the range for attack aircraft is planned in the near future. A data link pod and computer equipment with recording devices allow pilots to review a simulation of the fight on a monitor at a later time. The data recorded during the fight include aircraft altitude, inertial loading, and speeds. By correlating these data with aircraft configuration and strain gauge readings, a very real picture of fatigue damage for different types of usage is obtained, making the structural life monitoring program for all aircraft much more accurate than was possible in the past.

3. <u>Availability of Aircraft for Inspection</u>

A factor that will affect the economic savings and effectivness of the F/A-18 is the availability of aircraft at the depot for inspection. Every aircraft already at the depot for some reason is a potential AEP candidate, and could save the expense and disruption of bringing an aircraft into the depot specifically for AEP inspection. In many cases the aircraft would also be at least partially disassembled for some other reason, and concurrently performing the AEP inspection would save man-hours by avoiding duplicate disassembly. Wm. S. Burlem of NESO North Island has identified five reasons for inducting an AEP type aircraft into the depot. The five reasons are summarized below:

(1) Age Exploration--To assess statistically the material condition of the fleet.

(2) Modification Incorporation--To maintain air wings in an updated and homogeneous configuration.

(3) Corrosion Control--To assist the fleet in containing environmental degradation.

(4) Crash/Battle Damage Repair--To return damaged aircraft to useful service.

(5) Industrial Capability--To sustain a viable organic depot baseline.

Burlem noted that the first four of these reasons are related to aircraft condition, and the last is not. It

should further be noted that the reasons are mutually independent, and each is necessary and sufficient by itself to require an aircraft to be inducted for processing. Giving thought to scheduling and budgeting possibilities for each of these reasons leads to the following:

(1) Age Exploration--Schedules are based on flight-hours, calendar time, or some service parameter such as arrestments. Budgetary requirements can be calculated.

(2) Modification Incorporation--Modification schedules are normally connected to air wing deployment cycles, and occasionally to a flight safety modification applicable to all aircraft in a short time frame. Budgetary requirements can be statistically predicted using historical data.

(3) Corrosion Control--Corrosion control efforts are often connected to air wing deployment cycles, and may or may not be concurrent with modifications. Budgetary requirements for corrosion control can be statistically predicted using historical data.

(4) Crash/Battle Damage--Scheduling requirements are dependent upon operations. Historical data can be used to statistically predict budgetary requirements in the event of combat operations.

(5) Industrial Capability--A minimum constant induction rate schedule would be most effective. Budgetary requirements can be readily calculated based on the rate chosen.

Based on the above it can be seen that the AEP will probably not be the primary reason for inducting aircraft into the depot. It can also be seen that AEP funds can be saved by closely monitoring all aircraft scheduled to the depot and selecting AEP candidates from these aircraft when possible (the required match of aircraft history with the statistical basis). Another point that should be noted here based on the above is that there will still be a requirement for depot pipeline aircraft with the AEP. Experience will be needed to determine how much of a reduction in pipeline assets is possible with AEP.

VI. U.S. AIR FORCE PROCEDURES

A. OLDER AIRCRAFT PROGRAMS

Older U.S. Air Force (USAF) aircraft are treated very similarly to those in the Navy with allowances for the generally less severe operating environment. As an example, USAF F-4s are very similar to the Navy's, and have similar scheduled maintenance requirements. With this less modern structural design, a standard depot maintenance visit for all aircraft is considered a necessity, and all USAF F-4 models have a depot interval assigned.

All USAF aircraft were subjected to an Aircraft Structural Integrity Program (ASIP) [Ref. 25] analysis some years ago (1970s) to identify structural limits and crack growth characteristics. These data and operating requirements were used to determine the type of scheduled maintenance program possible. With older designs this has resulted in a scheduled depot requirement in most cases.

B. NEWER AIRCRAFT PROGRAMS

The latest USAF fighter aircraft, the F-15 and F-16, are maintained via procedures similar to those planned for use on the F/A-18. Scheduled maintenance requirements are based on an RCM analysis, and there is no scheduled depot maintenance requiring all aircraft to come to the depot on a fixed

interval. A sample of aircraft is looked at each year to maintain confidence in the design, and to identify the material condition of the force (fleet). The sampling program is called Analytical Condition Inspection or ACI. Most of the sample aircraft are inspected during modification incorporation to reduce disassembly expense, and to lessen the impact on the operating community. It is planned to wait until the F-16 reaches 4,000 flight-hours (half of its planned life) before inducting the first ACI aircraft [Ref. 26]. Reference 26 notes that USAF operating commands seem to prefer heavy periodic inspections as opposed to the smaller phased inspections used by the Navy for most organizational maintenance.

The F-15 was designed in the late 1960s and introduced into service around 1974. The F-15 is a large sophisticated fighter aircraft, but less complicated and sophisticated than the F-14. The F-16 was designed in the mid-to-late 1970s and was introduced into service prior to 1980. In comparison to the F-14 and the F-15 the F-16 is a smaller and less sophisticated single engine aircraft. The F-16 is also less sophisticated than the F/A-18. Recent maintenance man-hour per flight-hour (MMH/FH) values for the F-4E (latest model USAF F-4 fighter), F-15, and F-16 are given in Table IV. These data can be compared to those in Table I on page 65. The values are similar for aircraft designed at approximately the same time. It is noted that the F-4E is a newer

structural design that the F-4S and has an internal gun, but has a less sophisticated missile fire control system. Both of these F-4 models have leading edge maneuvering slats, the F-4S via retrofit. The F-4E has a SDLM equivalent requirement. It is also noted that the F-16 is a more mature program than the F/A-18 which produces lower MMH/FH values. The single engine of the F-16 also serves to reduce field level (I level) MMH/FH.

TABLE IV

AVERAGE MAINTENANCE MAN-HOURS PER FLIGHT-HOUR FOR CALENDAR YEAR 1983

	F-4D	F-15A/B	F-16A
Organizational	49.1	44.9	24.4
Field (I Level)	13.0	14.9	7.3
TOTALS	62.2	59.8	31.7

Source: Logistics Operations Center, Air Force Logistics Command, Wright-Patterson Air Force Base, Ohio

2,002 depot man-hours are scheduled for each F-15 ACI in 1984. These hours include disassembly, inspection, reassembly and check out, and 400 MMHs for correction of defects [Ref. 27]. The F-16 is not scheduled for ACI until 1987 or 1988 when the force leading aircraft will have

accumulated 4,000 flight hours. This information can be compared to the data in Table III on page 71. The comparison confirms that a mature ACI program such as that of the F-15 can be enormously less expensive than an ongoing SDLM program such as that for the F-14. The F-15 also has a good safety record. The relatively small number of man-hours for the F-15 ACI compared to the initial F/A-18 AEP estimate (2,002 versus 6,500) gives hope that the mature AEP for the F/A-18 will be significantly less expensive than 6,500 man-hours per aircraft. The lack of an ACI requirement for the F-16 until after it reaches 4,000 flight-hours (until recently an advanced age for a fighter aircraft) shows considerable confidence in the analyses supporting the design and the maintenance program.

C. PROGRAM REQUIREMENTS

The governing instructions for depot inspection of USAF aircraft [Refs. 28, 29, 30, and 31] are similar in concept to what the Navy is doing with RCM and the Age Exploration Program (AEP). The sample sizes used in the USAF program are smaller than those planned for use with the F/A-18, and give a lower level of confidence for finding a defect. The basis for the sample size is a double sampling program, which starts with a sample of 11 aircraft from a fleet of 200 or more aircraft, and requires a second sample of 13 additional aircraft if a defect is found in the first sample. This

program is intended to detect any defect existing in 20 or more percent of the fleet with a 90 percent probability [Ref. 29; pp. 2]. If more than one defect is found in the first sample, or if an additional defect is found during a required second inspection, it is assumed that the defect is present in 20 percent or more of the fleet and corrective action is initiated accordingly.

D. BASIS FOR THE PROGRAM

Discussions with cognizant USAF personnel revealed that the sampling requirements were designed some time ago and the detailed basis for the confidence levels chosen is not available today. AFLC Regulation 66-28 notes [Ref. 29; pp. 2] that,

> "The sample size and selection criteria specified do not constitute a statistically valid sample of the MDS population according to the statistical probability theory. However, they do provide the most practical sampling of the worst case aircraft to give the SM early indicators of the force airworthiness to determine the need for additional maintenance requirements or modifications."

VII. POTENTIAL AEP PROBLEMS AND FUTURE DIRECTIONS

A. POTENTIAL PROBLEMS WITH AGE EXPLORATION (AEP)

By looking backwards to the multifaceted analysis that leads up to the AEP, it is clear that the program is backed by considerable data. In comparison to previous design efforts leading to an aircraft with a scheduled maintenance program, there was a significant increase in the amount of attention given to individual failure consequences and maintenance requirements; however, just as in the past there is a chance of error or omission resulting in an unanticipated problem with the design. This chance or probability is much lower today considering the depth and breadth of the required analysis going into the final design and maintenance program, but considering the complexity of the systems involved it is a virtual certainty that there will be unanticipated problems with the new aircraft. This leaves the question of how an AEP-based maintenance program will handle these problems in comparison to the previous system where all aircraft were subjected to depot level inspection on some scheduled interval (SDLM).

Most individuals with experience in the maintenance of aircraft realize that the majority of problems (structural failures, flight control problems, electrical problems, etc.) have been found in the past more as a result of accident than

design. This doesn't say that the inspections required on older aircraft did not serve a purpose in many cases, only that there were a significant number of problems occurring that were not anticipated. Inspections currently required on older designs have been justified by an RCM type analysis and are valid for the design in question.

A plus for the old system (SDLM) was that more looking was going on so there was more of a chance of finding something, even if the discovery was inadvertent. On the negative side, the more disassembly that is done the more likelihood there is of creating a problem in doing the reassembly, and disassembling every aircraft is expensive and difficult to control from a cost standpoint (the larger the task the more difficult it is to control).

In the past the discovery of a new problem would require engineering investigation to determine the nature of the problem and what could or should be done to correct it. Prior to the development of MSG-1, MSG-2, and RCM, the investigative process was more difficult due to the lack of a comprehensive breakdown of all of the aircraft's systems and structure along with failure consequences. With the addition of this informational base and improved techniques of structural analysis, investigations of future problems should lead to better solutions in less time whatever the nature of the problem. A disadvantage compared to the current SDLM environment is the potential lack of ready access to

additional aircraft to rapidly expand the data base. The lack of available aircraft will create difficulties for fleet operators and engineering investigators unless there are modification lines handy at the depot or field activity so that downing and disassembling an aircraft of the required configuration and background will not be necessary.

The aircraft custodians (Commanders, Naval Air Forces, Pacific and Atlantic) and the depot will have to be more flexible under the AEP maintenance concept than has been required under the SDLM concept. There will be cases where one or more aircraft will have to be pulled out of service on short notice for an inspection to verify the extent and/or nature of a problem. This requirement is similar to current urgent action Airframe Bulletin (AFB) procedures, except that aircraft for an initial AFB look have usually been available at the depot and fleet operations are not disturbed until inspection procedures are prepared if a general inspection is necessary. The potential requirement to rapidly deploy depot inspection teams when a defect is found during and AEP inspection carries with it the problem of obtaining the associated funding to conduct needed inspections and/or repairs. This potential funding problem is recognized and addressed in reference 20, and efforts to identify funding procedures are in progress.

B. QUALITY OF THE DATA

The paramount issue with the AEP concept is the ability to gather good data. A statistical sampling program is of little value if valid data are not collected accurately. To insure valid and accurate data it is planned that engineering personnel will be used to record the results of AEP (Depot) inspections. In this way all defects found can be classified accurately as to their significance, and an accurate record maintained for future trend analysis. This requirement will necessitate a dedicated group of engineering personnel within the NESO (NAVAIR Engineering Support Office) at the rework activity to carry out this function. Contracted engineering support during particularly heavy surges of data gathering and/or analysis is feasible [Ref. 21; pp. 1-9].

Accuracy of data is also a major concern for the remainder of the AEP (non depot). Timely and accurate data will allow valid decisions on modifications to the initial scheduled maintenance program, particularly in terms of the tasks resulting from default decisions during the RCM analysis process (see paragraph IV.D). The NESO will need to work closely with the aircraft operators to insure a sound data base for task modification decisions.

C. PRIMARY RELIABILITY-CENTERED MAINTENANCE WEAKNESS

The most obvious weakness in the RCM analysis process [Ref. 7] is in the procedures used to determine the initial inspection thresholds. This part of the process is subject to individual interpretation, and two analysts of similar skill level could arrive at different intervals after analyzing the same item. Improvement in the system is needed, and until it occurs, the AEP is especially important. In the early stages of a program the AEP can insure that service intervals are driven outward to the maximum extent possible (the inherent reliability level of the equipment).

D. THE IMPORTANCE OF NON-DESTRUCTIVE INSPECTION

Effective non-destructive inspection (NDI) is essential to insure the quality of data. The success of the sampling inspection is closely tied to the quality of the NDI program. In light of demonstrated problems in this area in the past [Ref. 23] much attention to this area is required. As noted previously, the confidence levels expressed for the sampling plans assume a perfect inspection process. Successful defect detection rates as low as fifty percent have been realized in some cases [Ibid]. Continued improvement in this area can pay big dividends in terms of a higher success rate for inspections, and in terms of fewer inspection man-hours and shorter turnaround times. Large area inspection techniques

for composite structures is an NDI field that holds particular promise.

E. AEP (DEPOT) RELATIVE TO THE AIR FORCE SYSTEM

The primary difference between the USAF Analytical Condition Investigation (ACI) program for the F-15 fighter and the AEP (Depot) program for the Navy F/A-18 is the sample size and statistical basis used. The USAF has settled on a 90 percent confidence level of finding a defect that exists in 20 or more percent of the force (fleet for Navy). This results in a first sample size of 11 aircraft for a force of 200 or more aircraft based on a double sampling program. In double sampling a second sample is required if a defect is found in the first sample. The size of the second sample in this case is 13 additional aircraft [Ref. 29; pp 2].

The F/A-18 AEP (Depot) is starting with a sample size of 28 aircraft giving a 95 percent confidence level that a defect which exists in 10 percent or more of the fleet will be detected. The Navy approach is obviously more cautious, and stands less of a chance of being surprised by a major problem which could adversely impact fleet readiness. If a problem that impacts 20 percent or more of the fleet is not found until it has grown to more than 20 percent, a large safety, operational readiness, and financial problem is at the doorstep of the custodian. A larger sample size and confidence level reduces the risk significantly while still

retaining a considerable cost savings over SDLM. As experience is gained the validity of a given sample size may prove questionable, but the basis process will continue with larger or smaller samples used.

F. ARE THE ACQUISITION PROCEDURES WORTH THE EFFORT?

One could question the worth of the complex procedures used to acquire a new weapon system with respect to the cost in time more than in dollars. With life cycle cost analysis and attention to all of the maintainabillity and supportability items (LSA), the dollar cost of the procedures is hard to question. The delay time between the initial need and the first deployment is, however, something that is more vulnerable to questioning. Major acquisitions can take one to four years for each of the acquisition phases, and ten years or more from approval of the need by OSD to initial deployment is quite possible. Acquisition in half as much time was possible under the procedures that produced the F-4, although procurement costs could get out of control more easily in that system, and the less thoroughly tested and developed system might be too expensive to maintain at an acceptable level of readiness. The aircraft received as a result of the delay associated with the new acquisition process should be significantly better in terms of the much lower cost of ownership (acquisition and operation), should be more reliable and easier to maintain, and should be able

to perform its mission at least as well. The thrust of developments in the acquisition field is aimed at improving the system in terms of reducing the time required to obtain a new system. Hopefully, efforts in this direction will lead to a capability to acquire affordable, capable, and supportable weapon systems in a more timely manner.

G. DIRECTIONS FOR FUTURE MAINTENANCE PROGRAMS

Reviewing the background of the development of the scheduled maintenance requirements determination process reveals rapid growth with many changes over a relatively short timeframe, and the likelihood of more change and growth in the future. Present and future aircraft design programs will continue to emphasize reduction of maintenance requirements and life cycle cost as goals worthy of equal weight with performance specifications.

The probable increased length of the life cycle for newer weapon systems greatly increases the potential life cycle cost savings from reduced operating and maintenance costs. The increasing scarcity of funding for aircraft maintenance evident over the past decade will probably continue in the future. This makes the AEP or some type of sampling based inspection program an economic necessity for the future. With careful consideration of this requirement in the design process, and a thorough and thoughtful development of the maintenance program inspection requirements, future aircraft

operations should be at least as safe as in the past, and availability should be improved. This safe operation should be accomplished at considerable savings in funding required for maintenance man-hours and pipeline aircraft. Reductions in depot staffing is also a probable cost saving result as older aircraft are phased out and SDLM requirements are no longer present. The build-up of experience with the F/A-18 AEP will provide needed data on the exact magnitude of this potentially large saving.

With experience gained in the F/A-18 AEP, further improvements to the current system of developing scheduled maintenance programs should be possible, and this will aid the design of the next weapon system. This potential benefit is another reason that particular care must be taken in the implementation of the F/A-18 AEP to document procedures used and decisions made.

With advancing technology, significant additional reductions in the cost of maintenance for future aircraft should be possible. As an example, the USAF is citing eight to ten MMH/FH as a target for the ATF (Advanced Tactical Fighter) program which is at the end of the Concept Exploration Phase in the acquisition process at this time. Maintenance man-hour expenditures in this range, coupled with reduced requirements for maintenance personnel and test and support equipment, and with no requirement for scheduled depot maintenance will result in a weapon system that is

orders of magnitude less expensive to maintain and operate than is the case with older designs. A recent article on fighter design requirements of the future [Ref. 32] by an aircraft designer emphasized the above points in analyzing the key contributors to success in the last four major conflicts involving U.S. versus Soviet aircraft (Korea in 1951-53, Southeast Asia in 1962-73, the Middle East in the Yom Kippur War in 1973, and the Bekka Valley campaign in 1982). The article stresses the need for a balance between performance capabilities and number of aircraft. The author notes that without this balance, too few of an aircraft with tremendous performance capability, but which is too expensive to own and operate in adequate quantities, is as bad a situation as having large numbers of comparatively low performance easy targets. The article goes on to say:

> ".... In the future, technology needs to reflect this balance, particularly in the following areas:
>
> AFFORDABILITY. Most customers for fighters are required to buy the system lowest in cost that still meets their requirements. Technological leverage must not only improve performance but also prove cost-effective. ....
>
> AVAILABILITY. In its broadest definition, availability means airplanes on target when and where required. Examples of the importance of availability have been provided by the Israelis in their last two encounters. High sortie rate turned overall numerical inferiority into local numerical superiority. The next fighter should be designed for high reliability, maintainability, and supportability...."

The article notes that it is perhaps easier to say the words than to meet this challenge, but that the effort is necessary to obtain the weapon systems needed. The last three sentences in this quote highlight the fact that reduced maintenance requirements combined with improved reliability and maintainability not only reduce life cycle cost, but they also act as a force multiplier. This is particularly important in carrier operations since numerical inferiority is a strong possibility.

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